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Modification of Huffman Coding.

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THESIS

MODIFICATION OF HUFFMAN CODING

by

Suha Kılıç

March 1985

Thesis Advisor: R. W. Hamming

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Modification of Huffman Coding

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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I. THE INTRODUCTION

In a digital transmission system, the requirement to maximize the data transfer rate drives the redundancy of the source toward a minimum. One way to reduce the redundancy of the source is to encode the source information with a variable length code such as a Huffman Code [Refs. 1,2]. Such source code encoding assigns short bit sequences to source symbols with a high frequency of occurrence, and long bit sequences to source symbols with a low frequency of occurrence. The bandwith requirement is therefore dependent on the average code word lengths.

A. HUFFMAN CODING

Using only the probabilities of the various symbols being sent, Huffman Coding provides an organized technique for finding the code of minimum average length. The procedure is illustrated in the following example.

Suppose that we wish to code five symbols, S1, S2, S3, S4, and S5 with the probabilities 0.125, 0.0625, 0.25, 0.0625, and 0.5 respectively. The Huffman procedure can be accomplished in four steps.

Step 1. Arrange the symbols in order of decreasing probability. If there are equal probabilities, choose any of the various possibilities. See (Figure 1.1).

Step 2. Combine the bottom two entries to form a new entry with a probability equal to the sum of the original probabilities. If necessary, reorder the list so that probabilities are still in descending order. See (Figure 1.2). Note that the bottom entry in the right hand column is a combination of S2 and S4.

Symbol	Probability
S5	0.5
S3	0.25
S1	0.125
S2	0.0625
S4	0.0625

Figure 1.1 Step 1 of Huffman Coding

Symbol	Prob.	Prob.
S5	0.5	0.5
S3	0.25	0.25
S1	0.125	0.125
S2	0.0625	0.125
S4	0.0625	

Figure 1.2 Step 2 of Huffman Coding

Step 3. Continue combining in pairs until only two entries remain. See (Figure 1.3).

Step 4. Assign code words by starting at right with the most significant bit. Move to the left and assign another bit if a split occurred. The assigned bits are shown in parenthesis in Figure 1.4.

Finally, the code words are given in Figure 1.5.

Symbol	Prob.	Prob.	Prob.	Prob.
S5	0.5	0.5	0.5	0.5
S3	0.25	0.25	0.25	0.5
S1	0.125	0.125	0.25	
S2	0.0625	0.125		
S4	0.0625			

Figure 1.3 Step 3 of Huffman Coding

Symbol	Prob.	Prob.	Prob.	Prob.
S5	0.5	0.5	0.5	0.5 (0)
S3	0.25	0.25	0.25 (10)	0.5 (1)
S1	0.125	0.125 (110)	0.25 (11)	
S2	0.0625 (1110)	0.125 (111)		
S4	0.0625 (1111)			

Figure 1.4 Step 4 of Huffman Coding

S1 ------	110
S2 ------	1110
S3 ------	10
S4 ------	1111
S5 ------	0

Figure 1.5 Final Code Words

From Figure 1.5 we get code lengths (3, 4, 2, 4, 1), and the average the average length is given by

$$L = 0.125(3) + 0.0625(4) + 0.25(2) + 0.0625(4) + 0.5(1)$$

$$L = 1.875$$

The Huffman code is the shortest possible code, but the variance is given by

$$V = 0.125(3 - 1.875)^2 + 0.0625(4 - 1.875)^2 + 0.25(2 - 1.875)^2$$
$$+ 0.0625(4 - 1.875)^2 + 0.5(1 - 1.875)^2 = 1.109375$$

By comparison, Block Coding, which assignes codes of equal length to each symbol, would have produced an average length of 3 with zero variance.

B. VARIOUS CODES AND REDUCTION OF VARIANCE

Figure 1.6 shows three different codes for the same source symbols used above.

Symbol	Prob.	Code 1 (Huffman)	Code 2	Code 3
S5	0.5	0	0	00
S3	0.25	10	100	01
S1	0.125	110	101	10
S2	0.0625	1110	110	110
S4	0.0625	1111	111	111
Average length =		1.875	2	2.125
Variance =		1.109375	1	0.109375

Figure 1.6 Various Codes

The results of Figure 1.6 show that decreasing average length causes an increase in variance. A plot of the results is given in Figure 1.7.

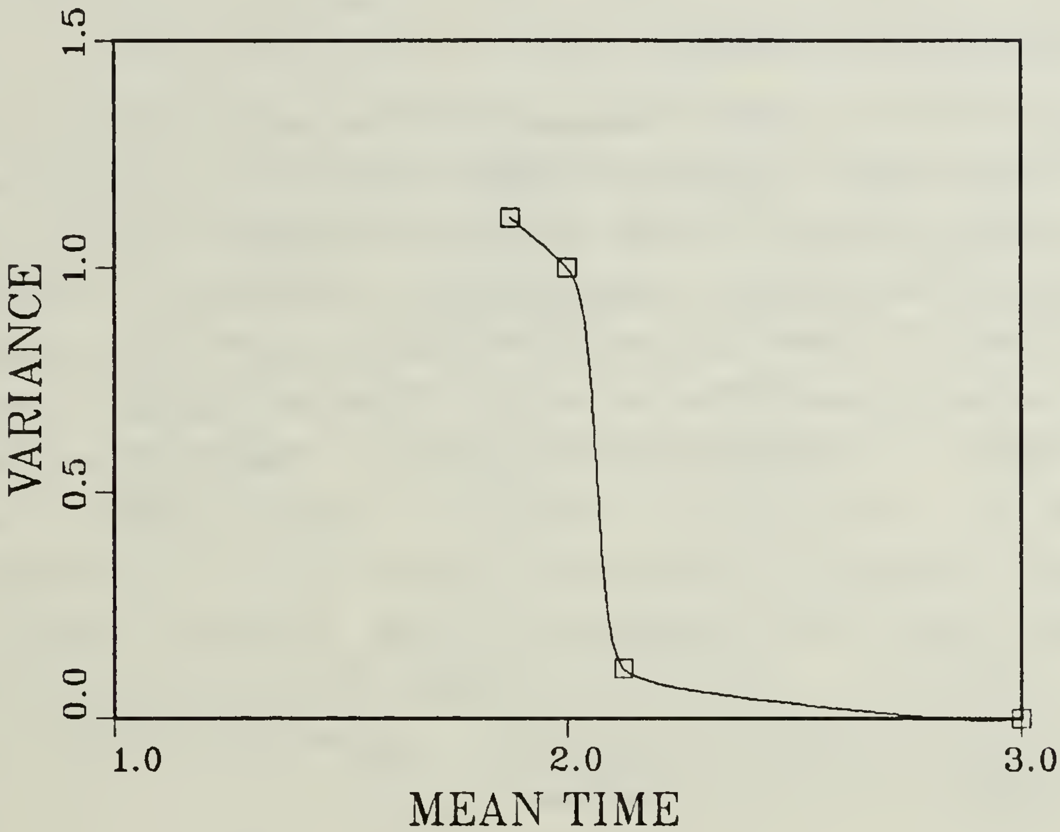

Figure 1.7 Variance Versus Mean Time for Five Symbols

II. MODIFICATION OF HUFFMAN CODING FOR A PARTICULAR ALPHABET

A. A PARTICULAR ALPHABET

The intent of this research in the early stages was to find an efficient variable length code for a Turkish On-Line communication device. For security reasons, Turkish letter frequencies in military usage are not available. Therefore, common usage letter and symbol frequencies were determined using two articles from a popular Turkish science magazine [Refs. 3,4]. The magazine articles, the Fortran language program and Statistical Analysis System (SAS) package program are given in Appendix A [Ref. 5]. The frequencies and other statistical characteristics obtained this way are given in Table 1. Table 2 contains the symbols re-arranged in order of decreasing frequency, along with their respective probabilities of occurance.

B. ASSIGNMENT OF THE CODES

Using the derived frequency data, the symbols of this alphabet were to be assigned various codes, but there are many other codes to be examined for the purpose of reduction of variance versus increase in mean time. This process was too complex and time consuming to do manually for an alphabet of 47 symbols. For this reason the author used a program written in List Programming (LISP) language, shown in Appendix B [Refs. 6,7]. This program is run with two parameters (N,E), to assign the code words to the symbols. These parameters serve the purpose of modifying the Huffman Coding process to obtain lower variance codes. Both parameters are based on the idea of shifting the combined entries higher than their positions in the Huffman Coding process.

Practically this assignment is expected to result in lower variance codes. [Ref. 1: p. 68]. The definitions of the parameters are given below.

(1) N is defined as the number of relative places a combined entry is moved, after positioning it in order of decreasing probability. If N is set to 0, we obtain Huffman coding, if N is set to 1, combined entries are moved one position higher than their position in the Huffman coding process. Setting N to 1, step 2 of the Huffman Coding process for the example given in the previous chapter can be modified as shown in Figure 2.1.

Symbol	Prob.	Prob.
S5	0.5	0.5
S3	0.25	0.25
S1	0.125	0.125
S2	0.0625	0.125
S4	0.0625	

Figure 2.1 Step 2 of Huffman Coding for N = 1

(2) The second parameter E, is a constant which is added to the probability sum of each combined entry when generating a code. This causes the combined entry to appear higher in the decreasing probability list (recall step 2 of the Huffman coding process described in the previous chapter), which results in a lower variance code. Like N, if 0 is assigned to E, the Huffman code will result. Setting E to

0.13, step 2 of Huffman Coding process for the example given in the previous chapter can be modified as shown in Figure 2.2. We do not need to worry that the sum of all the probabilities is no longer equal to one.

Symbol	Prob.	Prob.
S5	0.5	0.5
S3	0.25	0.255
S1	0.125	0.25
S2	0.0625	0.125
S4	0.0625	

Figure 2.2 Step 2 of Huffman Coding for E = 0.13

The Huffman code, which is obtained by setting N and E to 0, is given in Table 3. This table also includes the entropy of this particular alphabet. The entropy gives a lower bound on the amount of compression that can be achieved by any encoding using only the single letter frequencies, as done here. [Ref. 1: pp.104 -108]. The other codes, obtained with different N and E values, are given in Tables 4.1 through 4.40. These tables also include the average length and the variance of their respective code words.

TABLE 1

Symbol Characteristics of the Particular Alphabet

SYMBOL	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
.	182	182	1.017	1.017
(	12	194	0.067	1.084
)	15	209	0.084	1.168
;	11	220	0.061	1.229
-	3	223	0.017	1.246
space	2387	2610	13.339	14.585
,	219	2829	1.224	15.809
?	1	2830	0.006	15.814
:	6	2836	0.034	15.848
!	29	2865	0.162	16.010
"	20	2885	0.112	16.122
A	1687	4572	9.427	25.549
B	337	4909	1.883	27.432
C	293	5202	1.637	29.070
D	628	5830	3.509	32.579
E	1423	7253	7.952	40.531
F	64	7317	0.358	40.889
G	391	7708	2.185	43.073
H	104	7812	0.581	43.655
I	1884	9696	10.528	54.183
J	8	9704	0.045	54.227
K	691	10395	3.861	58.089
L	918	11313	5.130	63.219
M	527	11840	2.945	66.164
N	1183	13023	6.611	72.775
O	476	13499	2.660	75.434
P	123	13622	0.687	76.122
R	1089	14711	6.085	82.207
S	713	15424	3.984	86.192
T	575	15999	3.213	89.405
U	924	16923	5.163	94.568
V	156	17079	0.872	95.440
W	7	17086	0.039	95.479
X	1	17087	0.006	95.485
Y	480	17567	2.682	98.167
Z	177	17744	0.989	99.156
0	35	17779	0.196	99.352
1	24	17803	0.134	99.486
2	16	17819	0.089	99.575
3	13	17832	0.073	99.648
4	12	17844	0.067	99.715
5	15	17859	0.084	99.799
6	8	17867	0.045	99.844
7	5	17872	0.028	99.871
8	13	17885	0.073	99.944
9	10	17895	0.056	100.000

TABLE 2

Symbol Probabilities in Decreasing Order

SYMBOL	PROBABILITY	SYMBOL	PROBABILITY
space	0.13339	F	0.00358
I	0.10528	0	0.00196
A	0.09427	'	0.00162
E	0.07952	1	0.00134
N	0.06611	"	0.00112
R	0.06085	2	0.00089
U	0.05163	)	0.00084
L	0.05130	5	0.00084
S	0.03984	3	0.00073
K	0.03861	8	0.00073
D	0.03509	(	0.00067
T	0.03213	4	0.00067
M	0.02945	;	0.00061
Y	0.02682	9	0.00056
O	0.02660	J	0.00045
G	0.02185	6	0.00045
B	0.01883	W	0.00039
C	0.01637	:	0.00034
,	0.01224	7	0.00028
.	0.01017	-	0.00017
Z	0.00989	?	0.00006
V	0.00872	X	0.00006
P	0.00687	Q	0.00000
H	0.00581		

TABLE 3

Huffman Codes for the Particular Alphabet

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	010	'	100101101
I	101	1	0000011100
A	111	"	0000011111
E	0001	2	1001001011
N	0110	)	1001011001
R	1000	5	1001011000
U	1100	3	1001011110
L	1101	8	1001011101
S	00100	(	1001011111
K	00101	4	00000111010
D	00111	;	00000111011
T	01110	9	00000111101
M	01111	J	10010010101
Y	10011	6	10010010100
O	000000	W	10010111000
G	000010	:	10010111001
B	001100	7	000001111001
C	001101	-	0000011110000
,	0000010	?	00000111100011
.	0000110	X	000001111000100
Z	0000111	Q	000001111000101
V	1001000		
P	1001010		
H	00000110		
F	10010011		
0	100100100		

Entropy (H) = 4.27876

Mean Time (L) = 4.30771

Variance (V) = 1.91828

TABLE 4.1

Various Codes for the Particular Alphabet

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	100	'	011010001
I	110	1	101000100
A	0000	"	001010010
E	0011	2	001010011
N	0111	)	0110100110
R	0101	5	0110100000
U	1110	3	0110100111
L	1011	8	0110100100
S	00100	(	1010001110
K	00010	4	0110100101
D	00011	;	1010001100
T	01100	9	1010001101
M	01000	J	1010001011
Y	01001	6	1010001010
O	10101	W	01101000011
G	11111	:	10100011110
B	001011	7	011010000100
C	011011	-	101000111110
,	101001	?	101000111111
.	111100	X	0110100001010
Z	111101	Q	0110100001011
V	0010101		
P	0110101		
H	00101000		
F	10100000		
0	10100001		

N = 1 , E = 0.0 ;

Mean Time (L) = 4.31277

Variance (V) = 1.41646

Code No = 1

Table 4.2

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	101	'	001010011
I	110	1	001010001
A	0011	"	111011100
E	0101	2	100100010
N	0110	)	111011000
R	0111	5	100100011
U	1000	3	111011111
L	1111	8	111011001
S	00010	(	100100001
K	00011	4	100100000
D	00000	;	0010100100
T	00001	9	0010100101
M	01000	J	1110111011
Y	01001	6	0010100000
O	10011	W	0010100001
G	001011	:	1110111100
B	001000	7	1110111101
C	001001	-	111011101000
,	111010	?	111011101010
.	111000	X	111011101001
Z	111001	Q	111011101011
V	0010101		
P	1001001		
H	1001010		
F	1001011		
0	11101101		

N = 3 , E = 0.0 ;

Mean Time (L) = 4.3194

Variance (V) = 1.34446

Code No = 2

Table 4.3

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	101	'	10001000
I	0010	1	10001001
A	0011	"	11010010
E	0101	2	11010011
N	0111	)	11101010
R	1001	5	11101001
U	1111	3	11101000
L	1100	8	110101000
S	00010	(	110101110
K	00011	4	110101011
D	00000	;	110101111
T	00001	9	100010100
M	01000	J	100010101
Y	01001	6	111010110
O	11100	W	111010111
G	01100	:	1101010010
B	01101	7	1101010101
C	100011	-	11010100110
,	100000	?	11010101000
.	100001	X	11010100111
Z	111011	Q	11010101001
V	110110		
P	110111		
H	1101000		
F	11010110		
0	10001011		

N = 4 , E = 0.0 ;

Mean Time (L) = 4.36186

Variance (V) = 0.93749

Code No = 3

Table 4.4

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0001	'	11110101
I	0010	1	11101110
A	0011	"	11110110
E	1010	2	11101111
N	0110	)	11110111
R	1001	5	11101010
U	0100	3	11101011
L	0101	8	100000010
S	1100	(	100000110
K	1101	4	100000011
D	00000	;	100000111
T	00001	9	100000100
M	01110	J	111011000
Y	11111	6	100000101
O	11100	W	111011001
G	10110	:	1000000000
B	10111	7	1000000001
C	100001	-	10000000100
,	111100	?	10000000110
.	011110	X	10000000101
Z	011111	Q	10000000111
V	100010		
P	100011		
H	1110100		
F	11101101		
0	11110100		

N = 4 , E = 0.00100 ;

Mean Time (L) = 4.4168

Variance (V) = 0.68287

Code No = 4

Table 4.5

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0000	'	1010011
I	0001	1	01111000
A	0110	"	01111001
E	1000	2	01111011
N	1001	)	01001001
R	1011	5	01111110
U	1110	3	01111111
L	1111	8	01001010
S	00100	(	01111100
K	00101	4	01001011
D	01010	;	11011010
T	01110	9	01111101
M	11000	J	11011000
Y	01000	6	11011001
O	11010	W	011110101
G	10101	:	010010000
B	00110	7	010010001
C	00111	-	110110110
,	010011	?	110110111
.	010110	X	0111101000
Z	010111	Q	0111101001
V	110111		
P	101000		
H	110010		
F	110011		
0	1010010		

N = 8 , E = 0.0 ;

Mean Time (L) = 4.45705

Variance (V) = 0.52959

Code No = 5

Table 4.6

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0110	'	1111011
I	0111	1	1111000
A	1110	"	1111110
E	1011	2	1111001
N	1100	)	1111111
R	1001	5	1111100
U	01011	3	1111101
L	00000	8	0101000
S	00001	(	0101001
K	00100	4	00010010
D	00101	;	00010011
T	00110	9	00010000
M	00111	J	00010001
Y	01000	6	01010100
O	01001	W	01010101
G	10100	:	00010110
B	10101	7	00010111
C	11010	-	00010100
,	11011	?	00010101
.	000110	X	01010110
Z	000111	Q	01010111
V	100000		
P	100001		
H	100010		
F	100011		
0	1111010		

N = 7 , E = 0.01000 ;

Mean Time (L) = 4.53922

Variance (V) = 0.45146

Code No = 6

Table 4.7

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0101	'	1100001
I	0111	1	1100010
A	1011	"	1100110
E	1000	2	1100011
N	1110	)	1100111
R	00111	5	1010010
U	00000	3	1010011
L	00001	8	1010000
S	00010	(	1010001
K	00011	4	1010110
D	00100	;	1010111
T	00101	9	1010100
M	11110	J	1010101
Y	01000	6	00110100
O	01001	W	00110101
G	01100	:	00110110
B	01101	7	00110111
C	11010	-	00110000
,	11011	?	00110001
.	10010	X	00110010
Z	10011	Q	00110011
V	111110		
P	111111		
H	1100100		
F	1100101		
0	1100000		

N = 9 , E = 0.00750 ;

Mean Time (L) = 4.58711

Variance (V) = 0.42911

Code No = 7

Table 4.8

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1011	'	111001
I	1111	1	0000010
A	1100	"	0000011
E	1101	2	0101110
N	01010	)	0101111
R	01101	5	0101100
U	01110	3	0101101
L	00010	8	0111100
S	00011	(	0111101
K	00100	4	0110010
D	00101	;	0110011
T	00110	9	0110000
M	00111	J	0110001
Y	01000	6	0000000
O	01001	W	0000001
G	10000	:	0000110
B	10001	7	0000111
C	10010	-	0000100
,	10011	?	0000101
.	101000	X	0111110
Z	101001	Q	0111111
V	101010		
P	101011		
H	111010		
F	111011		
0	111000		

N = 11 , E = 0.01000 ;

Mean Time (L) = 4.65856

Variance (V) = 0.38929

Code No = 8

Table 4.9

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1010	'	111111
I	1011	1	111100
A	1100	"	111101
E	00000	2	111010
N	00001	)	111011
R	00010	5	0001100
U	01000	3	0001101
L	00100	8	0100100
S	00101	(	0100101
K	00110	4	0111000
D	00111	;	0111001
T	11100	9	0111010
M	01101	J	0111011
Y	01010	6	0111110
O	01011	W	0111111
G	10000	:	0111100
B	10001	7	0111101
C	10010	-	0100110
,	10011	?	0100111
.	110100	X	0001110
Z	110101	Q	0001111
V	011000		
P	110110		
H	011001		
F	110111		
0	111110		

N = 13 , E = 0.00250 ;

Mean Time (L) = 4.73389

Variance (V) = 0.34297

Code No = 9

Table 4.10

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1001	'	110001
I	1011	1	101010
A	00000	"	101011
E	00001	2	101000
N	00010	)	101001
R	00011	5	110110
U	00100	3	110111
L	00101	8	011000
S	11110	(	011001
K	11010	4	0011000
D	01101	;	0011001
T	01000	9	1111100
M	01001	J	1111101
Y	01010	6	1111110
O	01011	W	1111111
G	01110	:	0011010
B	01111	7	0011110
C	10000	-	0011011
,	10001	?	0011111
.	110010	X	0011100
Z	110011	Q	0011101
V	111000		
P	111001		
H	111010		
F	111011		
0	110000		

N = 10 , E = 0.01000 ;

Mean Time (L) = 4.82519

Variance (V) = 0.28005

Code No = 10

Table 4.11

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1101	'	111011
I	00010	1	111000
A	00011	"	111001
E	00100	2	101100
N	00101	)	101110
R	00110	5	101101
U	00111	3	111100
L	01000	8	101111
S	01001	(	111101
K	01010	4	100010
D	01011	;	100011
T	01100	9	100100
M	01101	J	100101
Y	01110	6	0000010
O	01111	W	0000011
G	10100	:	0000000
B	10101	7	0000001
C	11000	-	0000110
,	11001	?	0000111
.	100000	X	0000100
Z	100001	Q	0000101
V	100110		
P	100111		
H	111110		
F	111111		
0	111010		

N = 8 , E = 0.02500 ;

Mean Time (L) = 4.92818

Variance (V) = 0.19330

Code No = 11

Table 4.12

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	00000	'	011011
I	00001	1	011100
A	00011	"	011101
E	00101	2	011110
N	00111	)	100000
R	01000	5	011111
U	01001	3	100001
L	01011	8	011000
S	10100	(	100010
K	10101	4	011001
D	10110	;	100011
T	10111	9	100100
M	11100	J	100110
Y	11000	6	100101
O	11001	W	100111
G	11010	:	111010
B	11011	7	111011
C	11110	-	0011000
,	11111	?	0011010
.	000100	X	0011001
Z	000101	Q	0011011
V	001000		
P	001001		
H	010100		
F	010101		
0	011010		

N = 25 , E = 0.0 ;

Mean Time (L) = 5.06011

Variance (V) = 0.05707

Code No = 12

Table 4.13

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	011	'	001101001
I	101	1	001101010
A	111	"	001101011
E	0010	2	110010110
N	0101	)	110010111
R	1001	5	001101100
U	1101	3	001101101
L	00000	8	0000101000
S	00010	(	0000101010
K	00011	4	0000101001
D	01000	;	0000101100
T	01001	9	0000101011
M	10000	J	0000101101
Y	10001	6	0000101110
O	11000	W	0000101111
G	001100	:	1100101000
B	001110	7	1100101001
C	001111	-	1100101010
,	0000100	?	1100101011
.	0000110	X	0011010000
Z	0000111	Q	0011010001
V	1100100		
P	1100111		
H	00110111		
F	11001100		
0	11001101		

N = 0 , E = 0.00500 ;

Mean Time (L) = 4.31961

Variance (V) = 1.73177

Code No = 13

Table 4.14
Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	101	'	011110001
I	110	1	011110010
A	0011	"	011110011
E	0100	2	011110110
N	0101	)	011110111
R	1000	5	011110100
U	1001	3	011110101
L	1110	8	000000000
S	1111	(	000000001
K	00010	4	0000001010
D	00011	;	0000001011
T	00100	9	0000001000
M	00101	J	0000001001
Y	01100	6	0000001110
O	01101	W	0000001111
G	000001	:	0000001100
B	011111	7	0000001101
C	011100	-	0000111010
,	011101	?	0000111011
.	0000100	X	0000111000
Z	0000101	Q	0000111001
V	00001111		
P	00000001		
H	00001100		
F	00001101		
0	011110000		

N = 3 , E = 0.00250 ;
Mean Time (L) = 4.32665
Variance (V) = 1.59198
Code No = 14

Table 4.15

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	011	'	01001001
I	110	1	000011100
A	0001	"	000011101
E	0011	2	000011110
N	0101	)	000011111
R	1010	5	100101000
U	1111	3	100101010
L	00000	8	100101001
S	00100	(	100101011
K	00101	4	100101100
D	01000	;	100101101
T	10001	9	100101110
M	10011	J	100101111
Y	10111	6	0000110000
O	11100	W	0000110010
G	11101	:	0000110001
B	000010	7	0000110100
C	100100	-	0000110011
,	100000	?	0000110110
.	100001	X	0000110101
Z	101100	Q	0000110111
V	101101		
P	0100101		
H	0100110		
F	0100111		
0	01001000		

N = 0 , E = 0.01250 ;

Mean Time (L) = 4.33631

Variance (V) = 1.23500

Code No = 15

Table 4.16

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	101	'	1001111
I	111	1	00010000
A	0010	"	00010001
E	0100	2	10000110
N	0101	)	10000111
R	0110	5	001101110
U	0111	3	001101111
L	1101	8	001101100
S	00000	(	001101101
K	00001	4	000110010
D	00111	;	000110011
T	10010	9	000110000
M	10001	J	000110001
Y	11000	6	0011010010
O	000111	W	0011010011
G	000101	:	0011010000
B	001100	7	0011010001
C	100110	-	0011010110
,	110010	?	0011010111
.	110011	X	0011010100
Z	0001101	Q	0011010101
V	0001001		
P	1000010		
H	1000000		
F	1000001		
0	1001110		

N = 1 , E = 0.00750 ;

Mean Time (L) = 4.3443

Variance (V) = 1.35389

Code No = 16

Table 4.17

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	010	'	0111101
I	111	1	1100000
A	0001	"	1100001
E	0011	2	01101100
N	1001	)	01101110
R	1010	5	01101101
U	1101	3	01101111
L	00001	8	000001100
S	00101	(	000001101
K	01100	4	000001110
D	01110	;	000001111
T	10001	9	0000010010
M	10111	J	0000010011
Y	11001	6	0000010100
O	000000	W	0000010110
G	001001	:	0000010101
B	011010	7	0000010111
C	011111	-	00000100000
,	110001	?	00000100001
.	100000	X	00000100010
Z	100001	Q	00000100011
V	101100		
P	101101		
H	0010000		
F	0010001		
0	0111100		

N = 0 , E = 0.01500 ;

Mean Time (L) = 4.36739

Variance (V) = 1.24489

Code No = 17

Table 4.18

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	111	'	1000111
I	0001	1	00000100
A	0011	"	00000101
E	0100	2	00000110
N	0101	)	00000111
R	1010	5	110001010
U	0110	3	110001011
L	0111	8	110001000
S	00001	(	110001001
K	10000	4	110001110
D	11001	;	110001111
T	00100	9	110001100
M	00101	J	110001101
Y	10010	6	110000010
O	10011	W	110000011
G	10110	:	110000000
B	10111	7	110000110
C	000000	-	110000001
,	100010	?	110000111
.	110100	X	110000100
Z	110101	Q	110000101
V	1101100		
P	1101101		
H	1101110		
F	1101111		
0	1000110		

N = 3 , E = 0.01000 ;

Mean Time (L) = 4.37066

Variance (V) = 0.95923

Code No = 18

Table 4.19

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	111	'	01110001
I	0101	1	01110010
A	0110	"	01110011
E	1000	2	00011010
N	1001	)	00011011
R	1010	5	00011000
U	1011	3	00011001
L	1100	8	00000100
S	1101	(	00000101
K	00101	4	01110110
D	00001	;	01110111
T	01000	9	010011010
M	00010	J	010011011
Y	00111	6	010011000
O	01111	W	010011100
G	000000	:	010011001
B	000111	7	010011101
C	001000	-	0100111100
,	001001	?	0100111110
.	001100	X	0100111101
Z	001101	Q	0100111111
V	0111010		
P	0000011		
H	0100100		
F	0100101		
0	01110000		

N = 6 , E = 0.00100 ;

Mean Time (L) = 4.37112

Variance (V) = 1.03108

Code No = 19

Table 4.20

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	011	'	1010101
I	111	1	10001100
A	0001	"	10001101
E	0011	2	10001110
N	0100	)	10001111
R	0101	5	000001000
U	1100	3	000001001
L	1101	8	000001010
S	10100	(	000001011
K	10110	4	000001100
D	00100	;	000001110
T	00101	9	000001101
M	000000	J	100001000
Y	000011	6	000001111
O	100000	W	100001010
G	100010	:	100001001
B	101011	7	100001011
C	100100	-	100001100
,	100101	?	100001110
.	100110	X	100001101
Z	100111	Q	100001111
V	101110		
P	101111		
H	0000100		
F	0000101		
0	1010100		

N = 0 , E = 0.02000 ;

Mean Time (L) = 4.37334

Variance (V) = 1.35521

Code No = 20

Table 4.21

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	111	'	0000111
I	0011	1	00100010
A	0100	"	00100011
E	1000	2	00100000
N	1011	)	00100001
R	1100	5	001011110
U	1101	3	001011111
L	00000	8	001011010
S	01111	(	001011011
K	01101	4	001011000
D	00010	;	001011100
T	00011	9	001011001
M	10101	J	001011101
Y	01010	6	001010010
O	01011	W	001010011
G	10010	:	001010000
B	10011	7	001010001
C	001001	-	001010110
,	000010	?	001010111
.	011100	X	001010100
Z	011101	Q	001010101
V	011000		
P	011001		
H	101000		
F	101001		
0	0000110		

N = 4 , E = 0.01250 ;

Mean Time (L) = 4.39698

Variance (V) = 0.86542

Code No = 21

Table 4.22

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	111	'	0111101
I	0110	1	10000010
A	1001	"	10000011
E	1010	2	00000100
N	1011	)	00000101
R	1100	5	10000000
U	1101	3	10000110
L	00010	8	10000001
S	00001	(	10000111
K	01000	4	10000100
D	00101	;	10000101
T	00111	9	00000110
M	10001	J	01001010
Y	01110	6	00000111
O	01010	W	01001011
G	01011	:	01001000
B	000000	7	01001001
C	000110	-	01001110
,	000111	?	01001111
.	001000	X	01001100
Z	001001	Q	01001101
V	001100		
P	001101		
H	0111110		
F	0111111		
0	0111100		

N = 8 , E = 0.00250 ;

Mean Time (L) = 4.41819

Variance (V) = 0.88848

Code No = 22

Table 4.23

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0000	'	10001101
I	0001	1	11111010
A	0010	"	11111011
E	0011	2	11111000
N	0101	)	11111110
R	0110	5	11111001
U	0111	3	11111111
L	1100	8	10001110
S	1101	(	11111100
K	1110	4	10001111
D	10011	;	11111101
T	10100	9	01001010
M	10000	J	01001011
Y	01000	6	01001000
O	10111	W	01001001
G	11110	:	100100010
B	100010	7	100100011
C	010011	-	100100000
,	101010	?	100100001
.	101011	X	100100110
Z	101100	Q	100100111
V	101101		
P	1001010		
H	1001011		
F	10010010		
0	10001100		

N = 4 , E = 0.00250 ;

Mean Time (L) = 4.43677

Variance (V) = 0.70212

Code No = 23

Table 4.24

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0100	'	0000111
I	0101	1	01101110
A	0111	"	01101111
E	1000	2	01101010
N	1100	)	01101011
R	1010	5	01101000
U	1011	3	01101001
L	1110	8	01101100
S	1111	(	01101101
K	00000	4	01100010
D	00010	;	01100011
T	00011	9	01100000
M	10010	J	01100001
Y	10011	6	01100110
O	11010	W	01100111
G	11011	:	01100100
B	001101	7	01100101
C	000010	-	01110010
,	001011	?	00110011
.	001000	X	00110000
Z	001001	Q	00110001
V	001110		
P	001111		
H	0010100		
F	0010101		
0	0000110		

N = 4 , E = 0.02000 ;

Mean Time (L) = 4.46044

Variance (V) = 0.62683

Code No = 24

Table 4.25
Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0110	'	1100110
I	0111	1	1001010
A	1000	"	1001011
E	1010	2	1100000
N	1011	)	1100001
R	1101	5	0000100
U	1110	3	0000101
L	00000	8	01000100
S	00010	(	01000110
K	00011	4	01000101
D	00100	;	01000111
T	00101	9	01000000
M	10011	J	01000001
Y	00110	6	01000010
O	00111	W	01000011
G	01010	:	11001110
B	01011	7	11001111
C	11110	-	100100000
,	11111	?	100100010
.	110001	X	100100001
Z	000011	Q	100100011
V	010010		
P	010011		
H	1001001		
F	1100100		
0	1100101		

N = 11 , E = 0.0 ;
Mean Time (L) = 4.49867
Variance (V) = 0.50127
Code No = 25

Table 4.26

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0101	'	1011111
I	0110	1	0001000
A	0111	"	0001001
E	1001	2	0001110
N	1010	)	0001111
R	1100	5	00111000
U	1101	3	00111001
L	00100	8	00111010
S	00101	(	00111011
K	01000	4	00111110
D	01001	;	00111111
T	11100	9	00111100
M	11101	J	00111101
Y	10000	6	00110010
O	10001	W	00110011
G	11110	:	00110000
B	11111	7	00110001
C	000110	-	00110110
,	000101	?	00110111
.	000000	X	00110100
Z	000001	Q	00110101
V	000010		
P	000011		
H	101100		
F	101101		
0	101110		

N = 5 , E = 0.02500 ;

Mean Time (L) = 4.51559

Variance (V) = 0.51347

Code No = 26

Table 4.27

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0101	'	0111011
I	1000	1	0100110
A	1010	"	0100111
E	1100	2	0110110
N	1101	)	0110111
R	1111	5	0110100
U	00011	3	0111000
L	01000	8	0110101
S	01111	(	1011000
K	01100	4	0111001
D	10111	;	1011001
T	00100	9	1011010
M	00101	J	1011011
Y	00110	6	0001000
O	00111	W	0001001
G	10010	:	01001010
B	10011	7	01001011
C	11100	-	000000000
,	11101	?	000000010
.	000001	X	000000001
Z	000101	Q	000000011
V	000010		
P	000011		
H	0000001		
F	0100100		
0	0111010		

N = 13 , E = 0.0 ;

Mean Time (L) = 4.54577

Variance (V) = 0.47200

Code No = 27

Table 4.28

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	0101	'	1011011
I	0111	1	1110100
A	1000	"	1110101
E	1010	2	1011000
N	1111	)	1011110
R	1100	5	1011001
U	00001	3	1011111
L	00010	8	1011100
S	00011	(	1011101
K	10010	4	1001110
D	00100	;	1001111
T	00101	9	1110010
M	01000	J	1110110
Y	01001	6	1110011
O	01100	W	1110111
G	01101	:	1110000
B	11010	7	1110001
C	11011	-	0000010
,	001110	?	0000011
.	000000	X	00111100
Z	001100	Q	00111101
V	001101		
P	0011111		
H	1001100		
F	1001101		
0	1011010		

N = 11 , E = 0.00100 ;

Mean Time (L) = 4.56374

Variance (V) = 0.51457

Code No = 28

Table 4.29

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1010	'	1001011
I	1011	1	1000000
A	1100	"	1000001
E	1101	2	1001000
N	1110	)	1001110
R	1111	5	1001001
U	00000	3	1001111
L	00001	8	1001100
S	00100	(	1001101
K	00010	4	1000100
D	00011	;	1000101
T	01000	9	1000010
M	01001	J	1000011
Y	01010	6	0010100
O	01011	W	0010101
G	01100	:	0011000
B	01101	7	0011001
C	01110	-	0011110
,	01111	?	0011111
.	0011010	X	0011100
Z	0011011	Q	0011101
V	0010110		
P	0010111		
H	1000110		
F	1000111		
0	1001010		

N = 12 , E = 0.00250 ;

Mean Time (L) = 4.58022

Variance (V) = 0.60248

Code No = 29

Table 4.30

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1001	'	0001101
I	1010	1	0110100
A	1011	"	0110101
E	1100	2	1000010
N	1110	)	1000011
R	00000	5	0110000
U	00001	3	0110001
L	00010	8	1000000
S	00100	(	1000110
K	00101	4	1000001
D	00110	;	1000111
T	00111	9	1000100
M	01000	J	1000101
Y	01001	6	0110110
O	11110	W	0110111
G	11010	:	0001110
B	01110	7	0110010
C	01111	-	0001111
,	010111	?	0110011
.	010100	X	0101100
Z	010101	Q	0101101
V	111110		
P	111111	N = 13 , E = 0.00100 ;	
H	110110	Mean Time (L) = 4.60287	
F	110111	Variance (V) = 0.44151	
0	0001100	Code NO = 30	

Table 4.31

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1001	'	011001
I	1010	1	111000
A	1100	"	111001
E	1111	2	0000110
N	00010	)	0000111
R	00011	5	0111100
U	00100	3	0111101
L	00101	8	0111000
S	10111	(	0111001
K	00110	4	1011010
D	00111	;	1011011
T	01101	9	0111010
M	01000	J	1011000
Y	01001	6	0111011
O	01010	W	1011001
G	01011	:	0111110
B	10000	7	0111111
C	10001	-	0000100
,	000000	?	0000101
.	110100	X	0000010
Z	110101	Q	0000011
V	110110		
P	110111		
H	111010		
F	111011		
0	011000		

N = 12 , E = 0.00500 ;

Mean Time (L) = 4.66384

Variance (V) = 0.40074

Code No = 31

Table 4.32

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1100	'	100111
I	1101	1	101100
A	1110	"	101101
E	1111	2	100010
N	01110	)	100011
R	01101	5	0111100
U	10000	3	0111101
L	00000	8	0111110
S	00001	(	0111111
K	00100	4	0110010
D	00101	;	0110011
T	01000	9	0110000
M	01001	J	0110001
Y	01010	6	0001010
O	01011	W	0001011
G	10100	:	0001000
B	10101	7	0001001
C	001110	-	0001110
,	001111	?	0001111
.	001100	X	0001100
Z	001101	Q	0001101
V	101110		
P	101111		
H	100100		
F	100101		
0	100110		

N = 9 , E = 0.02000 ;

Mean Time (L) = 4.68298

Variance (V) = 0.42141

Code No = 32

Table 4.33

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1001	'	101110
I	1101	1	010101
A	1110	"	101111
E	00000	2	110010
N	00100	)	110011
R	00101	5	110000
U	00110	3	110001
L	00111	8	101000
S	01000	(	101001
K	01001	4	0000100
D	01011	;	0000101
T	01100	9	0001000
M	01101	J	0001001
Y	01110	6	0001010
O	01111	W	0001011
G	10000	:	0001110
B	10001	7	0001111
C	101010	-	0001100
,	101011	?	0001101
.	101100	X	0000110
Z	101101	Q	0000111
V	111100		
P	111101		
H	111110		
F	111111		
0	010100		

N = 15 , E = 0.00250 ;

Mean Time (L) = 4.75953

Variance (V) = 0.37566

Code No = 33

Table 4.34

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1010	'	111111
I	1101	1	111100
A	1110	"	111101
E	00011	2	101100
N	01000	)	101101
R	00000	5	110010
U	00001	3	110011
L	00100	8	011100
S	00101	(	011101
K	00110	4	100010
D	00111	;	100011
T	01010	9	100000
M	01011	J	100001
Y	01100	6	0100100
O	01101	W	0100101
G	011110	:	0001010
B	011111	7	0001011
C	110000	-	0001000
,	110001	?	0001001
.	101110	X	0100110
Z	101111	Q	0100111
V	100100		
P	100101		
H	100110		
F	100111		
0	111110		

N = 13 , E = 0.01000 ;

Mean Time (L) = 4.79792

Variance (V) = 0.42646

Code No = 34

Table 4.35

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1011	'	111001
I	1100	1	111100
A	00010	"	111101
E	00011	2	111010
N	00100	)	111011
R	00101	5	110100
U	00110	3	110101
L	00111	8	101000
S	01110	(	101001
K	01000	4	100010
D	01001	;	100011
T	01010	9	011110
M	01011	J	011111
Y	01100	6	0000010
O	01101	W	0000011
G	10010	:	0000000
B	10011	7	0000110
C	100000	-	0000001
,	100001	?	0000111
.	101010	X	0000100
Z	101011	Q	0000101
V	110110		
P	110111		
H	111110		
F	111111		
0	111000		

N = 16 , E = 0.00250 ;
Mean Time (L) = 4.85151
Variance (V) = 0.31030
Code No = 35

Table 4.36

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1110	'	101011
I	1111	1	100100
A	00000	"	100101
E	00001	2	100110
N	00011	)	110000
R	00100	5	100111
U	00111	3	110001
L	01000	8	101000
S	01010	(	110010
K	01100	4	101001
D	01101	;	110011
T	10001	9	110100
M	01110	J	110110
Y	01111	6	110101
O	10110	W	110111
G	10111	:	0011010
B	001100	7	0011011
C	000100	-	1000000
,	000101	?	1000010
.	001010	X	1000001
Z	001011	Q	1000011
V	010010		
P	010011		
H	010110		
F	010111		
0	101010		

N = 21 , E = 0.0 ;

Mean Time (L) = 4.8695

Variance (V) = 0.33162

Code No = 36

Table 4.37

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1110	'	100101
I	00000	1	110110
A	00001	"	110111
E	00010	2	110000
N	00011	)	110010
R	00100	5	110001
U	00101	3	110100
L	00111	8	110011
S	01010	(	111100
K	01011	4	110101
D	01100	;	111101
T	01101	9	111110
M	01111	J	111111
Y	10101	6	101000
O	10000	W	101001
G	10001	:	0100100
B	10110	7	0100101
C	10111	-	1001110
,	010011	?	1001111
.	001100	X	0111000
Z	001101	Q	0111001
V	010000		
P	010001		
H	100110		
F	011101		
0	100100		

N = 20 , E = 0.0 ;

Mean Time (L) = 4.93958

Variance (V) = 0.20452

Code No = 37

Table 4.38

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1110	'	101101
I	1111	1	100010
A	00010	"	100011
E	01010	2	101110
N	01011	)	110010
R	01100	5	101111
U	01101	3	110011
L	01110	8	110000
S	01111	(	110001
K	10010	4	101000
D	10011	;	101001
T	11010	9	000000
M	11011	J	001000
Y	001010	6	000001
O	001011	W	001001
G	000010	:	001110
B	000011	7	001111
C	010010	-	001100
,	010011	?	001101
.	010000	X	000110
Z	010001	Q	000111
V	101010		
P	101011		
H	100000		
F	100001		
0	101100		

N = 13 , E = 0.02000 ;

Mean Time (L) = 4.94386

Variance (V) = 0.41804

Code No = 38

Table 4.39

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1111	'	011000
I	00000	1	001001
A	00001	"	011110
E	01011	2	011001
N	00010	)	100010
R	00011	5	011111
U	00101	3	100011
L	00110	8	100100
S	00111	(	110010
K	01000	4	100101
D	01001	;	110011
T	10100	9	110000
M	10101	J	110001
Y	10110	6	110110
O	10111	W	110111
G	11100	:	110100
B	11101	7	110101
C	100000	-	0101010
,	100001	?	0101011
.	100110	X	0101000
Z	100111	Q	0101001
V	011100		
P	011101		
H	011010		
F	011011		
0	001000		

N = 10 , E = 0.02000 ;

Mean Time (L) = 4.95533

Variance (V) = 0.22069

Code No = 39

Table 4.40

Various Codes for the Particular Alphabet (cont'd.)

SYMBOL	CODE WORDS	SYMBOL	CODE WORDS
space	1111	'	101101
I	00000	1	110010
A	00001	"	110011
E	01010	2	101110
N	00011	)	101111
R	00110	5	000100
U	00111	3	111010
L	10000	8	000101
S	10001	(	111011
K	10010	4	111000
D	10011	;	111001
T	10100	9	011010
M	10101	J	011011
Y	11010	6	011000
O	11011	W	011001
G	001000	:	011110
B	001001	7	011111
C	001010	-	011100
,	001011	?	011101
.	010010	X	010110
Z	010011	Q	010111
V	010000		
P	010001		
H	110000		
F	110001		
0	101100		

N = 11 , E = 0.02500 ;

Mean Time (L) = 4.99572

Variance (V) = 0.26248

Code No = 40

III. THE EVALUATION OF RESULTS

To gain a better understanding of the relative merits of the various experimental codes, a graph of their respective mean times and variances is given in Figure 3.1. The figure emphasizes that a small increase in mean time can result in a marked reduction in variance. The dotted line represents the minimum variance found for the corresponding mean time, and the boxes correspond to experimental codes which meet the minimum variance criteria.

Figure 3.2 also displays the experimental codes which have minimum variance for a given mean time. The points numbered 1 through 12 correspond to the codes given in Tables 4.1 through 4.12. This figure includes the Huffman code and the block code as the extreme points. The Huffman code represents minimum mean time and maximum variance while the block code has zero variance but greatly increased mean time. (For an alphabet of 47 letters Block Coding Gives an average length of 6 with zero variance).

The data for the figures appears in Table 5. This table also gives a summary of the reductions in variance achievable, with the differing amounts of mean time for the particular alphabet. The Huffman code is used as the base for computing the increments in mean times and the decrements in variances of these codes.

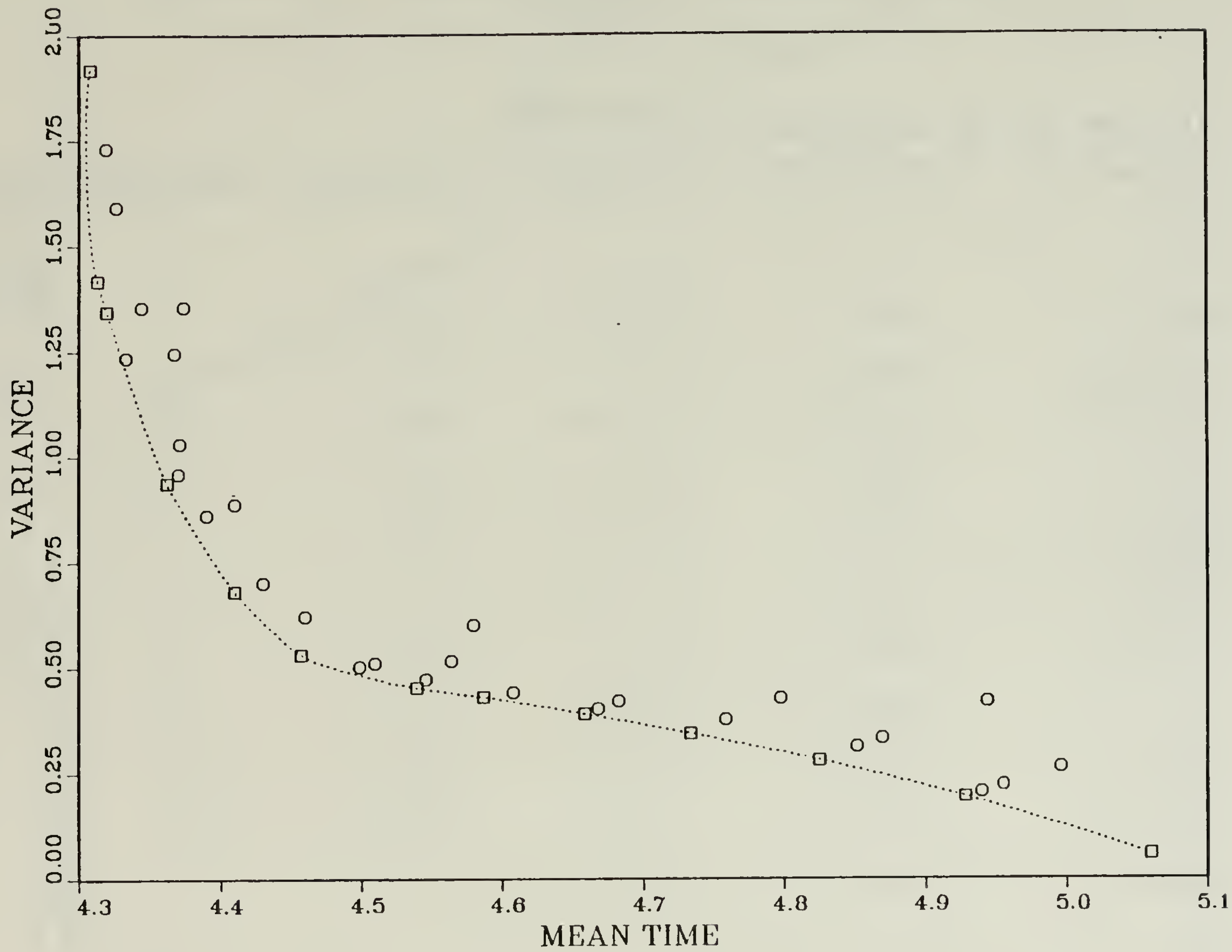

Figure 3.1 Variance - Mean Time Trade-off for the Particular Alphabet

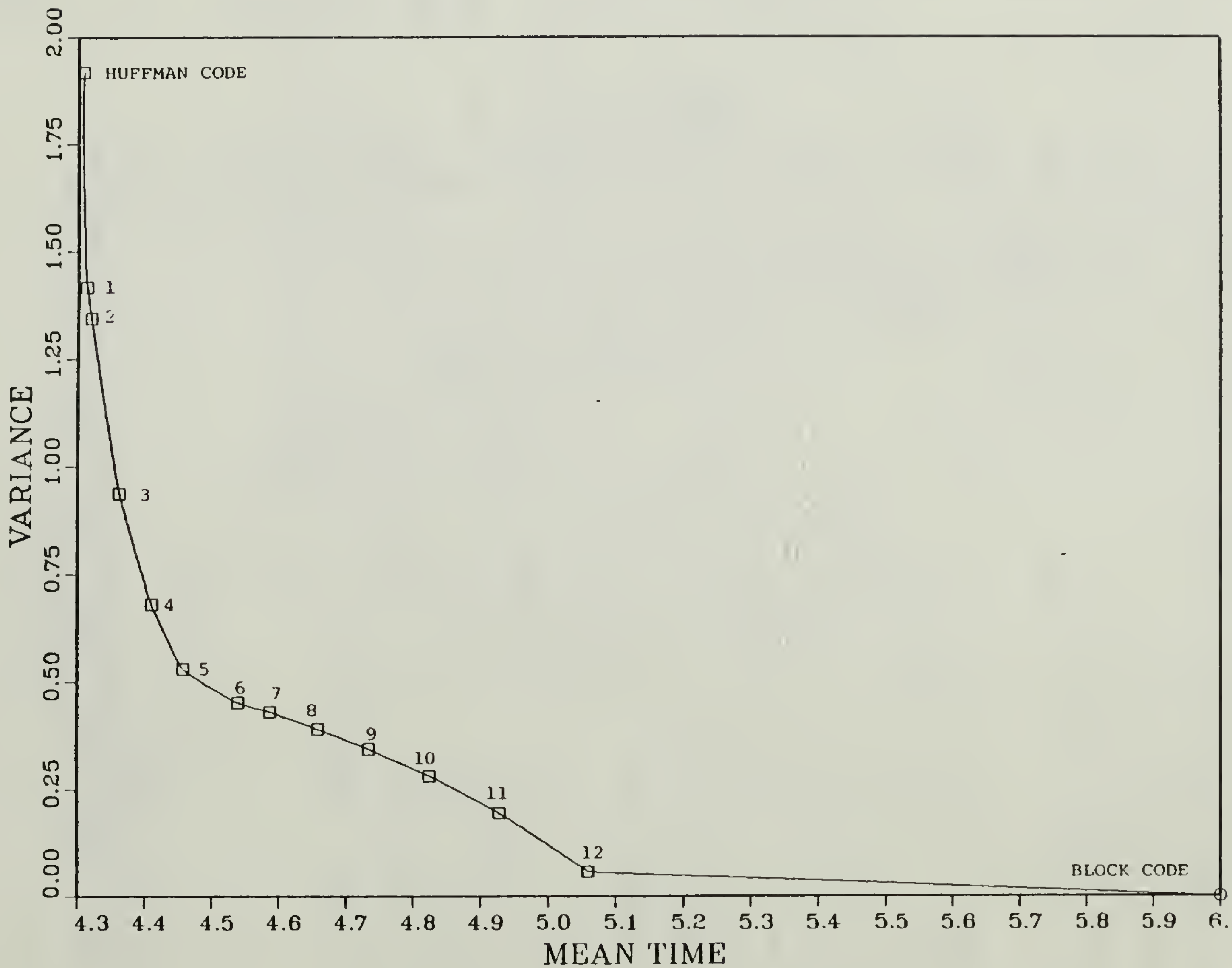

Figure 3.2 Lower Bound for Variance Reduction

TABLE 5

Data for Figure 3.1 Through 3.3

Code No	Table No	Mean time	Variance	Sacrifice in Mean Time	Gain in Variance
Huffman	3	4.30771	1.91828	0	0
1	4	4.31277	1.41646	0.00506	0.50182
2	4.1	4.3194	1.3444	0.01169	0.57388
3	4.2	4.36186	0.93749	0.05415	0.98079
4	4.3	4.4168	0.68287	0.10909	1.23541
5	4.4	4.45705	0.52959	0.14934	1.38869
6	4.5	4.53922	0.45146	0.23151	1.46682
7	4.6	4.58711	0.42911	0.2794	1.48917
8	4.7	4.65856	0.38929	0.35085	1.52899
9	4.8	4.73389	0.34297	0.42618	1.57531
10	4.9	4.82519	0.28005	0.51748	1.63823
11	4.10	4.92818	0.1933	0.62047	1.72498
12	4.11	5.06011	0.05707	0.75339	1.86121
Block code		6	0	1.69229	1.91828

Using the same table, a graph of the sacrifice in mean time versus the decrease in variance is given in Figure 3.3. Note that the graph includes segments almost parallel to the axis. These parallel segments simply show that further attempts at optimization are redundant for little gain in one variable causes significant loss in the other (Note that the segment between the Huffman code and code 2 is almost parallel to the vertical axis and the segment between code 12 and the block code is almost parallel to the horizontal axis). Consequently, better mixes of mean time and variance can be obtained using the segment between code 2 and code 12.

The selection of the codes depends on the output rate required. The term output rate is defined as the capacity of a processor for handling the traffic. The output rate of an On-Line communications device should be chosen so that on the average it can handle the input rate. When variations occur communications processors put the excess digits (0 and 1) in a buffer. These excess digits are later transmitted on the first in first out (FIFO) basis. The size of the FIFO buffer should be chosen to accomodate the maximum queue length. If, under extreme conditions, this is exceeded overflow is said to have occured, and some digits may be lost. The buffer size gives a further way of selecting among the various codes.

An example is included to find the maximum number of digits in the buffer during the transmission of two articles given in Appendix A. There are only two absolute rates available to be chosen as output rate, Huffman and Block code, and the latter would give little insight into the problem. For this example, the output rate chosen is 4.30771 bits per unit time representing the minimum mean time for the particular alphabet, obtained by Huffman Coding. Each code in Table 5 is then used to transmit the

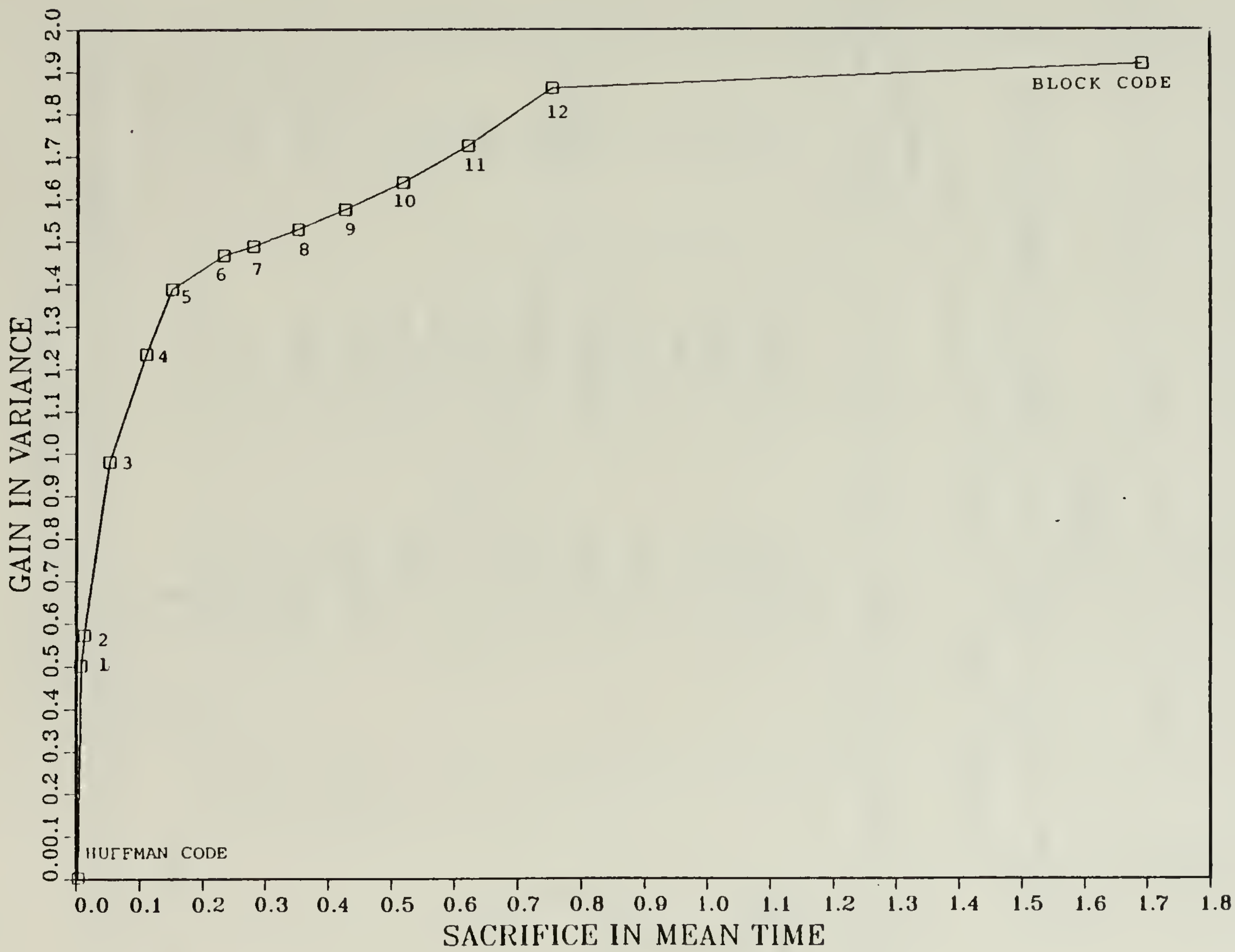

Figure 3.3 Sacrifice in Mean Time Versus Decrease in Variance

magazine articles so that their respective buffer requirements could be determined. The Statistical Analysis System (SAS) program used by the author for this purpose is given in Appendix C. The result of the experiment is summarized in Table 6 and a graph of the maximum buffer length versus the mean time is given in Figure 3.4.

TABLE 6

Maximum Buffer Length for Minimum Output Rate

Output Rate = 4.30771 bits/unit time

Code No	Table No	Mean time	Variance	Maximum Buffer Length
Huffman	3	4.30771	1.91828	66
1	4	4.31277	1.41646	52
2	4.1	4.3194	1.3444	47
3	4.2	4.36186	0.93749	42
4	4.3	4.4168	0.68287	62
5	4.4	4.45705	0.52959	68
6	4.5	4.53922	0.45146	97
7	4.6	4.58711	0.42911	176
8	4.7	4.65856	0.38929	261
9	4.8	4.73389	0.34297	1468
10	4.9	4.82519	0.28005	3102
11	4.10	4.92818	0.1933	4945
12	4.11	5.06011	0.05707	7305
Block code		6	0	24124

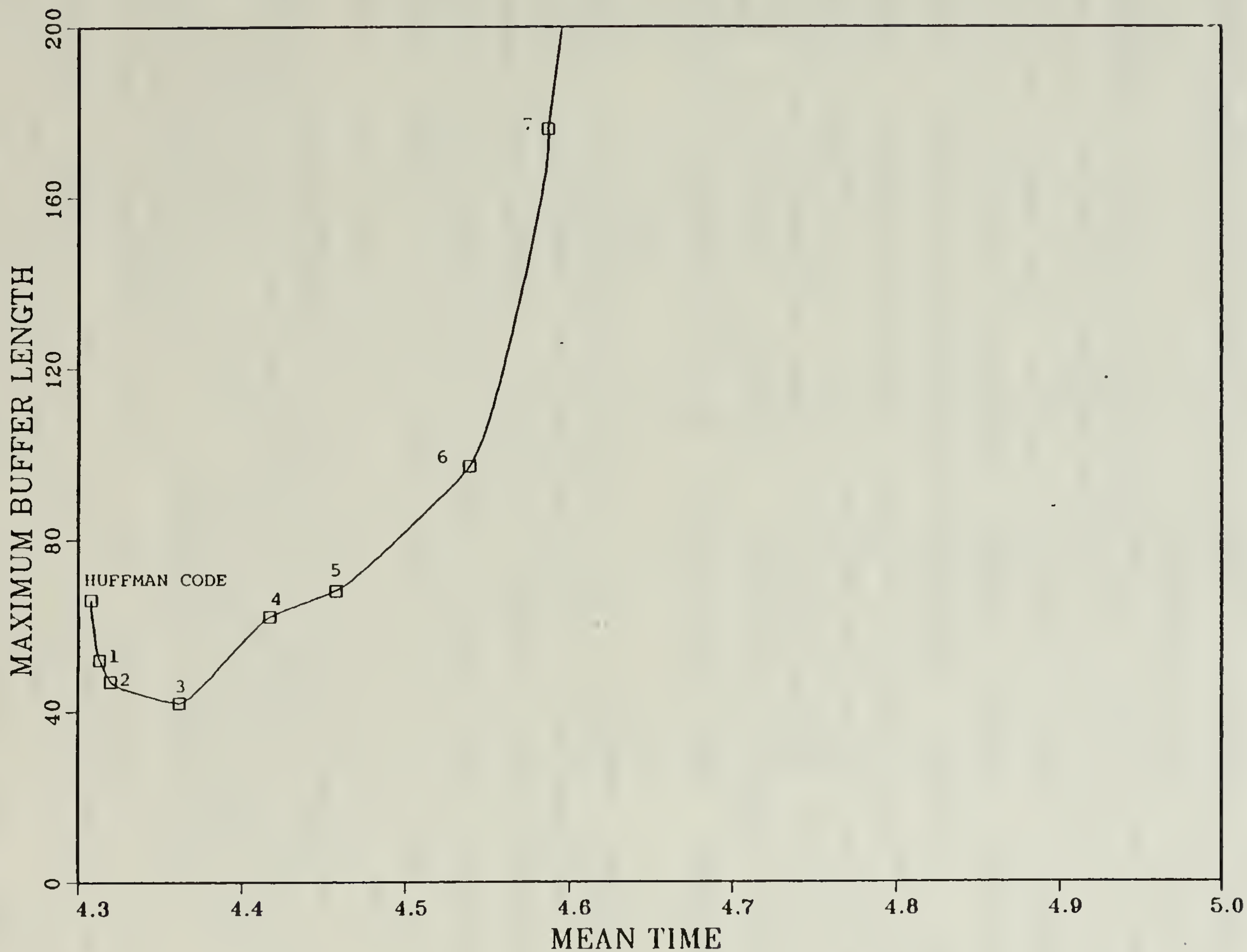

Figure 3.4 Maximum Buffer Length Versus the Mean Time

The results show that using code 3 (which is given in Table 4.3) gives the best result in terms of minimum delay incurred during the transmission of the articles. Although Huffman Coding produces the minimum average length code, because of its large variation, it causes more delay at some part of the transmission than code 3. This shows that an urgent short message may take much longer than expected as a result of the large variance.

Bear in mind that the maximum buffer size depends on two effects. First, except for the Huffman code, we are trying to send more than the rate can handle, and hence there is a linear growth of the buffer size with the length of the message. Second, the buffer size depends on the variance, and with longer messages we expect that the maximum fluctuation will grow like the square root of the message length. Table 6 clearly demonstrates that near Huffman Code the gain due to the drop in variance is greater (for this length message used) than the loss due to the increase in the mean time.

Any other output rate can be chosen between the mean times of Huffman and Block codes and the same experiment can be conducted. Five output rates were arbitrarily chosen by the author and the obtained results are summarized in Table 7. Note that as the desired output level is increased the codes which give the best results shift from code 3 towards code 12, getting further apart from the Huffman code.

Once again, remember that optimum point of a subsystem may be less significant than the optimum of the system as a whole. Often system performance is spoiled when a particular aspect is optimized. For Huffman coding the optimization for minimum average length causes a large variance. The thesis is an example of the general rule that when one aspect has been optimized it is to the detriment of most other aspects of the system, and optimizing for minimum

TABLE 7

Maximum Buffer Length for Different Output Rates

Output rates are given in bits/unit time below.

Code No	4.4	4.5	4.6	4.7	4.8
Huffman	58	54	51	48	45
1	48	44	41	38	35
2	44	40	37	34	31
3	38	34	31	28	25
4	42	38	35	32	29
5	36	30	26	23	20
6	42	26	22	19	15
7	63	28	23	20	16
8	115	36	19	15	12
9	211	77	25	18	12
10	1343	187	57	22	15
11	3185	1278	177	59	18
12	5545	3638	1731	226	81
Block code	22365	20457	18550	16643	14736

length produced a large variance. It was natural to suspect that by giving up a little in the mean time could result, if done properly, in a great gain (near the optimum) in the reduction of variance.

APPENDIX A
THE MAGAZINE ARTICLES AND PROGRAMS

A. THE MAGAZINE ARTICLES

Because this research is for an On-Line system, it is important to include the frequency of spaces in the text. To allow for this in the program, slashes were used instead of spaces.

The first article titled "Strange Shapes of Modern Ships" is given below (the slashes between the words are not shown).

BIR DERGININ RESSAMI, EN GUCLU VINCLERIN YAPAMADIGI ISI BASARARAK, 50.000 TONLUK BIR "OKYANUS DEVI"NI SUDAN CIKARDI VE BOYLECE, GEMININ BURNUNDAKI YUMRUBAS "BALB" ORTAYA CIKMIS OLDU. GEMININ KIC TARAFINDA DA BAZI YENILIKLER GOZE CARPIYORDU. BUNLARIN SIRRI ACABA NE OLABILIRDI? OTOMOBIL YAPIMCILARININ YENI GELISTIRDIKLERI MODELLERI DENEDIKLERI "RUZGAR TUNELLERI"NIN BIR BENZERI DENIZ TEKNELERI UZERINDE CALISAN MESLEKDASLARI ICIN DE GECERLI OLUYOR. ONLARIN DA YENI TEKNE MODELLERINI DENEDIKLERI "TEST HAVUZLARI" VAR. YENI GEMILER, ANCAK, BU HAVUZLARDA YAPILAN DENEYLERIN OLUMLU SONUCLAR VERMESINDEN SONRA, INSA EDILMEK UZERE KIZAGA KONUYOR. BU ARADA, GEMI MUHENDISLERININ ISLERI, KARA ARACLARI UZERINDE UGRAS VEREN MESLEKDASLARININ ISLERINDEN BIRAZ DAHA GUC. BU GUCLUK, DAHA MODEL ASAMASINDA BASLAR. DENEYLERI YAPILAN GEMI MODELLERI, YETERINCE BUYUK OLDUGU ZAMAN, DENEYLERDEN ALINAN OLCUM SONUCLARI, ISTENILENI VEREBILMEKTEDIR. GUCLUGU YARATAN IKINCI ETKEN DE, DUNYAMIZIN "SU" VE 'HAVA' OLARAK BILINEN IKI ELEMANINDAN KAYNAKLANMAKTADIR. BIR KARA TASITINDA, KAROSERI SADECE RUZGARA KARSI KOYMAK ZORUNDA OLMASINA KARSIN, BIR TEKNENIN

HEM DALGAYA VE HEM DE, RUZGARA KARSI KOYMASI GEREKIR. ESKI TARIHLERDE INSA EDILMIS GEMILERDE, BURUNLAR KESKINLESTIRILIR VE BOYLECE SUYUN DAHA AZ BIR DIRENIMLE YARILMASI SAGLANIRDI. ANCAK, BU IS, ASLINDA HIC DE GORUNDUGU KADAR BASIT DEGILDIR. GEMI HESAPLARI, SUALTINDAN ATESLENEN BIR ROKETIN HESAPLARINDAN DAHA KARMASIK VE GUCTUR. BIRAZ ONCE BELIRTTIGIMIZ GIBI BIR GEMI, SU VE HAVA ORTAMINDA SEYREDER. BU NEDENLE DE, OZELLIKLE HAVANIN VE SUYUN BIRLESTIGI NOKTA, MUHENDISLER ICIN BIR "BILMECE"DIR. DENEY HAVUZLARINDAN ALINAN SONUCLAR OKYANUSLAR ICIN DE GECERLI OLDUGUNDAN; BU BENZER ILISKILERDEN YARARLANAN GEMI MUHENDISLERI, DENEYLERINI DENEY HAVUZLARINDA YAPMAKTADIRLAR. GEMIYE HAREKET VEREN PERVANE, TEKNEYI ILERIYE ITERKEN, GEMININ BURNUNDA BIR DALGA OLUSUR. BU DALGA, BURUNDA, YANLARDA, DIPTE VE KICTA GEMIYI YALAYARAK GECER. ANCAK, ANILAN DALGA ALISILAGELEN TIPTE BIR DALGA OLMAYIP, SAGA-SOLA KARISIK HAREKETLER YAPAN SULAR HALINDEDIR. GEMI BURNUNDA OLUSAN VE TEKNE TARAFINDAN ILETILEN BU SU KITLELERI, GEMI BURNUNUN GENISLIGI ORANINDA ARTAN BIR YIGILMA YAPARAK, ISTENILMEYEN BIR DIRENC OLUSTURUR (SEKIL 1). ISTENILMEYEN BU DIRENCIN ETKISINI AZALTABILMEK ICIN, GEMININ BURNUNDA YUMRUBAS DENILEN VE MAHMUZU ANDIRAN BIR CIKINTI YAPILIR. YUMRUBASIN ETKISI SOYLE ACIKLANABILIR: YUMRUBASLI BIR TEKNE, ONUNDE IKI DALGA TEPESI OLUSTURUR. BUNLARDAN, TEKNENIN OLUSTURDUGU DALGA TEPESI, YUMRUBASIN OLUSTURDUGU DALGANIN CUKURUNU DOLDURARAK, GEMI BURNUNDAKI YIGILMAYI ONLER. (SEKIL 2) SONUC OLARAK DA, ISTENILMEYEN DALGA YOK EDILIR. YUMRUBAS ADI VERILEN BU YENI BURUN TIPI, AMERIKALI GEMI DAVID TAYLOR"UN BULUSUDUR. YUZYILIMIZIN BASLARINDA TAYLOR, YUMRUBASLI GEMILERIN, DIGERLERINE KIYASLA DAHA KUCUK DALGALAR OLUSTURDUGUNU TESPIT ETMIS VE BUNUN TEORISI DAHA SONRA GELISTIRILMISTIR. ANCAK, TUM OLASILIKLARI AYDINLIGA KAVUSTURACAK KESIN FORMULLER GUNUMUZDE DAHI TAM OLARAK SAPTANMIS DEGILDIR. YUMRUBAS TEORISININ GELISMESINI

ASAGIDAKI MADDELERLE ACIKLAYABILIRIZ: 1. SEYIR HALINDEKI BIR GEMI, ONUNDE BUYUK BIR DALGA TEPESI OLUSTURARAK ILERLER. 2. SU YUZEYININ HEMEN ALTINDA HAREKET ETTIRILEN BIR KURE, ARKASINDA BIR DALGA CUKURU OLUSTURUR. 3. GEMI MODELININ BURNUNA BIR KURE YERLESTIRILEREK, KURENIN OLUSTURDUGU DALGA CUKURU ILE GEMI MODELININ OLUSTURDUGU DALGAYI CAKISTIRACAK BIR DENEY UYGULAMASI GERCEKLESTIRILIR. 4. DENEYDE, DALGA CUKURUNUN DALGA TEPESINI YUTTUGU GORULUR. 5. DALGA TEPESI YUTULDUGUNDAN; ISTENILMEYEN DIRENC ETKISINI KAYBEDER. SONUC OLARAK, GEMI MODELI DAHA BUYUK BIR HIZ KAZANIR VEYA HAREKETI ICIN GEREKLI OLAN GUC AZALIR. ALINAN BU SONUC, GEMININ TUKETTIGI YAKITTA HIC DE AZIMSANAMAYACAK BIR TASARRUF SAGLANDIGINI ORTAYA KOYAR. ARMATORLERIN YUMRUBASLI GEMI SIPARISLERINE AGIRLIK VERMELERINDEN SONRA, MUHENDISLERIN ISLERI DAHA DA GUCLESMISTIR. ILK ZAMANLARDA YUMRUBASLAR, YOLCU VE SAVAS GEMILERINDE UYGULANIYORDU. BUNUN DA NEDENI, ANILAN GEMILERIN SEFERLERINI GENELLIKLE SABIT BIR SU KESIMINDE YAPMALARI IDI. OYSA, ARMATORUN SIPARISE BAGLADIGI YUK GEMILERINDE SU KESIMI (DRAFT), GEMILERIN YUKLU VEYA BOS OLMALARINA GORE, DEGISEBILDIGI ICIN, GEMI BURNUNDA YER ALAN YUMRUBAS, ETKINLIK POZISYONUNU KORUYAMAMAKTADIR. GEMI, YUKUNU ALARAK SEFERE CIKTIGINDA; YUMRUBAS, SUALTINDA, KALARAK, ETKINLIGINI SURDURMEKTE ISE DE, YUKUN BOSALTILMASINDAN SONRA, SU YUZEYINE CIKMAKTA VE SONUC OLARAK, ETKINLIGINI KAYBETMEKTEDIR. BU DURUM, YUMRUBASIN GEMI BURNUNDA NEREDE YER ALMASI GEREKTIGI SORUNUNU ORTAYA CIKARMISTIR. DAHA SONRA, YUMRUBAS, GEMI BURNUNUN BIRAZ DAHA ASAGISINA ALINARAK, SUYUN ALTINDA BIRAKILMIS VE ISTENILEN SONUCA KISMEN DE OLSA ULASILMISTIR. YUMRUBASI SADECE SUALTINDA BIRAKMAKLA SORUNLARA COZUM GETIRILEMEMEKTEDIR. CUNKU, HER TEKNE KENDINE OZGU BIR DALGA SEKLI OLUSTURMAKTA VE BU NEDENLE DE, YUMRUBASIN, KULLANILACAGI TEKNE ILE UYUM SAGLAYACAK OZELLIKLERE SAHIP OLMASI GEREKMEKTEDIR. GEMI MUHENDISLERININ GOGUSLEMEK ZORUNDA OLDUKLARI BU GUCLUKLER,

YENI ARASTIRMA ALANLARININ DOGMASINA YOL ACMIS VE BU KEZ DE, ARASTIRMALAR GEMININ KIC TARAFINDA YOGUNLASMISTIR. YAKLASIK 20 YIL KADAR ONCE, HAMBURGLU GEMI MUHENDISI ERNST NONNECKE, YENI BIR KIC FORMU GELISTIRMIS ISE DE, ONUN BU BULUSU ANCAK SON YILLARDA DEGER KAZANMAGA VE DIKKAT CEKMEGE BASLAMISTIR. NITEKIM, NONNECKE'NIN BULUSU, BIR KORE TERSANESINDE 2 KONTEYNER GEMISINDE UYGULAMAYA KONULMUSTUR. TEORIK CALISMALAR HAMBURG"DA BASLAMIS VE BUNU IZLEYEN DENEYLERDE, INSA EDILECEK GEMININ BIR MODELI, BOYU 300 M. VE DERINLIGI 18 M. OLAN BIR DENEY HAVUZUNA CEKILEREK, NONNECKE'NIN GELISTIRDIGI KIC FORMUNUN USTUNLUGU KABUL EDILMISTIR. BU TIP ASIMETRIK KIC FORMU: SANCAK TARAFI CUKUR VE ISKELE TARAFI DISA DOGRU BOMBELIDIR. BU FORMUN OZELLIGI, SUYUN AKISINI DUZELTEREK, DOGRUDAN PERVANEYE VERMESIDIR. NONNECKE TIPI KIC FORMU TEORISI SU SEKILDE ACIKLANABILIR: SIVI ICINDE HAREKET EDEN BIR GOVDE, SUYU BAS TARAFINDAN YARAR. YARILAN SU, GOVDENIN KIC TARAFINDA YINE BIRLESMEK EGILIMI GOSTERIRKEN, BU KEZ DE GEMININ PERVANESI ILE KARSILASIR. GEMININ HAREKET YONUNE GORE, SAGA DOGRU DONEN PERVANE, SUYU TEKNENIN SANCAK (SAG) TARAFINDAN ASAGIYA ITER, BUNA KARSIN, ISKELE TARAFINDAN (SOL), YUKARIYA DOGRU ITILEREK, TEKNENIN KIC TARAFINDA BIRLESME EGILIMI GOSTEREN SU, BIRLESEMEDEN PERVANENIN AKIMINA KAPILIR. CEKILEN SUALTI FOTOGRAFLARI ILE TESPIT EDILEN BU OLAY, SUYUN GEMIDE ISKELE TARAFININ GEREKTIRDIGI ITICI GUCU OLUSTURAMADAN, YUKARIYA DOGRU ITILDIGI GERCEGINI ORTAYA KOYMUSTUR. BU OLAY UZERINDE DURAN NONNECKE, ISKELE TARAFINDAN PERVANEYE YONELEN SU AKISINI DUZENLEYEBILMEK ICIN GEMIDE SANCAK VE ISKELE TARAFLARININ PERVANEYE YAKIN OLAN KISIMLARINDA, TASARLADIGI FORM DEGISIKLIKLERINI GERCEKLESTIRMISTIR. BUNA GORE, GEMININ SANCAK TARAFI CUKURLASTIRILMIS; ISKELE TARAFINDA ISE, CUKURLUGUN YERINI YUMUSAK BIR BOMBE ALMISTIR (SEKIL 5). SONUC OLARAK, SUYUN DAGILMAKSIZIN VE TURBULANSA UGRAMAKSIZIN, PERVANEYE AKABILMESI SAGLANMISTIR. SEKIL 3 VE

5 ESKI VE YENI TIP IKI GEMININ EN KESIT EGRILERINI VERMEKTEDIR. ESKI TIP BIR GEMIDE EN KESIT EGRILERI SIMETRIK BIR BICIM GOSTERMEKTE VE GEMININ ORTASINDA DUZ BIR CIZGI BOYUNCA BIRLESMEKTEDIR (SEKIL 3). DIGER TIP KIC FORMUNDA ISE, ANILAN EGRILER ASIMETRIK OLARAK GELMEKTE VE GEMININ ORTASINDA "S" SEKLINDEKI BIR CIZGI UZERINDE TOPLANMAKTADIR (SEKIL 5). SEKIL 4 VE 6'DA, ESKI VE YENI TIP KIC FORMLARININ BIRER PROFILI ILE PERVANEYE DOGRU YONELEN SUYUN AKISI GORULMEKTEDIR. ESKI TIP KIC FORMUNDA (SEKIL 4); PERVANEYE DOGRU AKIS YAPAN SU, PERVANE ILE KARSILASTIGINDA TURBULANSA UGRAMAKTA VE DOLAYLI OLARAK DA, GEMI DIESELININ PERVANEYE AKTARDIGI GUCTE KAYIBA YOL ACMAKTADIR. NONNECKE TIPI KIC FORMUNDA ISE, PERVANEYE YONELEN SUYUN AKISI DUZENLENMIS (SEKIL 6) VE DUZENLENEN SU, TURBULANSA UGRAMADAN, PERVANE TARAFINDAN ITILEREK, PERVANENIN VERIMI ARTIRILMIS VE GEMININ DAHA AZ BIR GUCLE DAHA BUYUK BIR HIZ KAZANMASI SAGLANMISTIR. "THEA S" ADLI 124 METRELIK GEMIDE YAPILAN DENEYLER, BU YENI KIC FORMUNUN GUNDE 2.000 LITRELIK BIR YAKIT TASARRUFU SAGLADIGINI ORTAYA KOYMUSTUR. ESKI TIP GEMI FORMLARININ GECERLI OLDUGU GUNLERE KIYASLA, YAKIT FIATLARININ BUGUN 10 KAT ARTTIGI GOZ ONUNDE TUTULURSA, GEMILERE SAGLANAN YAKIT TASARRUFUNUN NE KADAR ONEMLI OLDUGU VE MODERN GEMILERIN NICIN BOYLE GARIP BICIMLERDE INSA EDILDIGI SORUSU KENDILIGINDEN AYDINLIGA KAVUSABILIR.

The second article titled "Story of the Space Shuttle" is given below (the slashes between the words are not shown).

I970'LERE DEK DAYANAN UZAY MEKIGI PROJESININ TEMEL AMACI, UZAYA DAHA UCUZ VE DOLAYISIYLA DAHA SIK GITMEKTIR. MEKIKTEN ONCE UZAYA ATILAN INSANLI VE INSANSIZ UYDULAR, SONDA VE ROKETLER SADECE BIR KEZ KULLANILABILIYORDU VE BU NEDENLE MALIYETLERI YUKSEK OLUYORDU. UZAY MEKIGI PROJESI ILE INSANOGLU, AYNI UZAY ARACINI SUREKLI KULLANMA OLANAGINA

KAVUSTU. BU PROJENIN EN BELIRGIN OZELLIGI UCAK TEKNOLOJISI ILE UZAY TEKNOLOJISINI BIR ARAYA GETIRMESIDIR. SISTEM GENELDE UC ANA BOLUMDEN OLUSMAKTADIR: 1) YORUNGE ARACI DA DENEN UZAY GEMISININ KENDISI; 2) BUYUK DIS YAKIT TANKI; 3) DIS YAKIT TANKININ HER IKI YANINDA BULUNAN KATI YAKITLI ROKETLER. SISTEMI FIRLATMA ANINDA, GEMININ ARKASINDA BULUNAN ANA MOTORLAR VE IKI FIRLATICI ROKET ATESLENIR. BU ISLEMIN SONUNDA, OTUZ MILYON NEWTON'LUK COK BUYUK BIR FIRLATMA KUVVETI, SISTEMI HAVALANDIRIR. HAVALANDIKTAN BIR DAKIKA SONRA SISTEMIN SURATI, SES SURATINI ASAR. BU SIRADA GEMININ ICINDE OLSANIZ VE KENDINIZI TARTSANIZ, YERYUZUNDE 60 KILO GELEN VUCUDUNUZUN, IKI DAKIKA ICINDE SISMANLAMIS OLMAMASINA KARSIN, 180 KILO GELDIGINI GORURSUNUZ. BU ILGINC DURUM, ARACIN IVMESININ, CEKIM IVMESINDEN UC KAT FAZLA OLMASINDAN KAYNAKLANMAKTADIR. HAVALANDIKTAN SONRA KATI YAKITLI ROKETLERIN YAKITLARI BITER VE DIS YAKIT TANKINDAN AYRILIRLAR. BU ANDA GEMI, 50 KM. YUKSEKLIKTE VE HIZI SAATTE 5.000 KM'YE ULASMISTIR. AYRILAN ROKETLER, ILK HIZLARINDAN DOLAYI DERHAL ASAGIYA DUSMEZLER. 50 KM'DE AYRILAN BU ROKETLER, 67 KM'YE DEK CIKAR VE SONRA DUSMEYE BASLAR. DUSERKEN, YUZEYDEN YAKLASIK 3 KM. YUKSEKLIKTEN, UC EVRELI PARASUT SISTEMI CALISIR VE DUSUSUN HIZINI AZALTIR. DENIZE DUSEN ROKETLER, SU YUZEYINE DEGDIKLERI ANDA PARASUTLERDEN AYRILIR VE ALT TARAFTA BULUNAN OZEL BOLMELER SISEREK, ROKETLERIN BATMAMALARI SAGLANIR. DAHA SONRA BUNLAR DENIZDEN TOPLANIR, GEREKLI ONARIM VE BAKIM YAPILARAK, BIR SONRAKI UCUS ICIN HAZIRLANIRLAR. BU KATI YAKITLI ROKETLERIN KALKISTAKI AGIRLIGI, YAKLASIK 580 TONDUR VE 11.800.000 NEWTON'LUK BIR ITME MEYDANA GETIRMEKTEDIR. UZUNLUGU 45.5 METRE, SILINDIRIK GOVDENIN CAPI ISE 3.7 METREDIR. UZAY GEMISININ ANA MOTORLARINA YAKIT VEREN BUYUK DIS TANK ISE YERDEN 200 KM. YUKSEKLIKTE IKEN YAKITI BITTIGINDE ARACTAN AYRILIR. 20 KATLI BIR APARTMAN YUKSEKLIGINDE (50.M) OLAN BU BUYUK SILINDIRIK TANKIN CAPI 30 METREDIR. YAPIMI ICIN 30 TON

ALUMINYUM KULLANILAN BU TANKIN BIR KEZ KULLANILMASI, BIRCOK KISININ NASA'YI ELESTIRMESINE NEDEN OLMAKTADIR. CUNKU MEKIKTEN AYRILAN TANK, DAHA SONRA DUNYA ATMOSFERINE GIREREK YANMAKTADIR. NASA MUHENDISLERI BU TANKLARDAN NASIL YARARLANACAKLARINI DUSUNMEKTEDIRLER. HAZIRLANAN BIR PROJEYE GORE, 1990'DAN SONRA KURULMASI BEKLENEN UZAY ISTASYONUNUN, BU TANKLARDAN YIRMISININ BIR ARAYA GETIRILEREK YAPILMASI ONERILMEKTEDIR. MARTIN MARIETTA AEOROSPACE SIRKETI'NIN GELISTIRILMIS PROGRAMLAR BASKANI OLAN FRANK WILLIAMS'A GORE GEMI, TANKINI UZAYDA BIRAZ DAHA SONRA BIRAKACAK. O ZAMAN TANK, YER ATMOSFERINE DUSMEYECEK, GEMIYI IZLEYEREK ISTENEN YORUNGEYE OTURTULMASI SAGLANACAK. DENEYLERIN YAPILACAGI VE ICINDE RAHATCA YASANABILECEK SAGLAMLIKTA OLAN BU SILINDIRLER UC UCA EKLENDIGINDE, ISTENEN UZAY ISTASYONUNUN HEM DAHA KISA ZAMANDA, HEM DE DAHA EKONOMIK BIR SEKILDE YAPILABILECEGI ILERI SURULUYOR. UZAY GEMISININ ON GOVDESI VE MURETTEBAT BOLUMU, ALUMINYUMDAN YAPILMIS UC KATTAN OLUSMAKTADIR. EN UST KATTA, YORUNGE ARACININ KENDISINI, TUM UZAY GEMISI SISTEMINI VE TASINAN YUKU YONETEN, DENETLEYEN KUMANDA SISTEMI YER ALMAKTADIR. BU KATTA, UC ASTRONOT ISKEMLESI BULUNMAKTADIR. ORTA KAT, UCUS UZMANI TASIMA VE YASAM BOLUMU OLARAK AYRILMISTIR. AYRICA BU BOLUM, GEMININ YUK TASIYAN KARGO BOLUMU ILE BAGLANTILIDIR. ALT KATTA ISE CEVRE KONTROL GERECLERI YER ALMAKTADIR. GEMININ ORTA BOLUMU, YUK TASIYAN KARGO BOLUMUDUR VE UZAYA GIDERKEN USTTEN ACILAN IKI KAPAK ILE ORTULMEKTEDIR. UZAYDA BU KAPAKLAR ACILARAK, UYDULARI YORUNGEYE OTURTMAK, YURUYUS YAPMAK GIBI CESITLI GOREVLER YERINE GETIRILMEKTEDIR. ARKA GOVDE VE MOTOR YUVALARINI TASIYAN SON BOLUM, YORUNGE ARACININ EN KARMASIK PARCASIDIR. SADECE 8 DAKIKA SUREYLE ATESLENEN VE YORUNGEYE ERISMEZDEN ONCE 6 MILYON NEWTON'LUK FIRLATMA KUVVETI YARATAN UC ANA MOTOR BU BOLUMDEDIR. ANA MOTORLAR SUSTUKTAN SONRA GEMIYI YORUNGESINE OTURTAN IKI ROKETTEN OLUSAN YORUNGE MANEVRA SISTEMI DE BU ARKA BOLUMDEDIR. SON OLARAK BU BOLUMDE 38'I

ANA, 6'SI DUYARLI OLMAK UZERE TOPLAM 44 KUCUK ROKETTEN OLUSMUS, TEPKI-DENETIM SISTEMI BULUNMAKTADIR. BU SISTEM, ARACIN (YORUNGE ICINDE KALMA KOSULU ILE) KONUMUNU VE UC EKSENI BOYUNCA DONME HAREKETLERINI SAGLAMAKTADIR. YUKARIDA KISACA OZELLIKLERINI TANITMAYA CALISTIGIMIZ UZAY GEMISI ILK UZAY UCUSUNU, 3 YILLIK BIR GECIKMEDEN SONRA, 1981 YILINDA YAPTI. UCUSA HAZIRLANAN 4 UZAY GEMISINDEN ILK YAPILANI, COLOMBIA ADINI TASIYORDU. UCUS KOMUTANI VE PILOT, ILK GEMI SEYRININ PERSONELIYDILER. 12 NISAN 1981 GUNU COLOMBIA FLORIDA'DAKI FIRLATMA USSUNDEN HAVALANDI. DUNYA CEVRESINDE 36 TUR ATAN GEMI KALKISTAN 54.5 SAAT SONRA, 14 NISAN GUNU YERYUZUNE DONDU. UCUS BASARILI GECMISTI AMA; GEMIYI YUKSEK SICAKLIKTAN KORUYAN KORUMA FAYANSLARI ONEMLI DERECEDE HASARA UGRAMISTI. HASARA NEDEN OLAN SICAKLIK, OZELLIKLE ARAC DUNYA'YA DONERKEN, ATMOSFERDEKI SURTUNMEDEN KAYNAKLANIYORDU. IKINCI UCUS, I4 KASIM 1981 GUNU GERCEKLESTIRILDI. BES GUN OLARAK DUSUNULEN UCUS PROGRAMI YARIDA KESILDI VE GEMI IKI GUN SONRA YERYUZU'NE DONDU. BU UCUSUNDA HAVA KIRLILIGI, DENIZ ARASTIRMALARI GIBI BIR TAKIM BILIMSEL ARASTIRMALAR YAPILDI. AYRICA, KANADALILARIN YAPTIGI HERHANGI BIR YONE DOGRU 15.6 METRE UZANABILEN, GEMI DISINDAKI BIR NESNEYI TUTMAK ICIN VEYA ICINDEKI BIR ALETI TUTUP UZAYA BIRAKABILMEK ICIN KULLANABILECEK, KIMININ VINC, KIMININ ROBOT, BAZILARININ DA MEKANIK KOL DEDIGI BIRIMI DENEDILER. BU UCUSTA GEMI, BIRINCIYE GORE DAHA AZ HASARA UGRAMISTI. UCUNCU UCUS, 22 MART 1982 GUNU BASLADI VE ILK KEZ SEKIZ GUN SURDU. GEMI, PLANLANAN SEYRINI BIR GUN GECIKMEYLE 30 MART'TA TAMAMLADI. BU SEYIRDE, KOMUTAN VE PILOT, NORMAL CALISMALARIN YANI SIRA, BIR COK SEYLE DE UGRASTILAR. BUNLAR UZAY TUTMASI, RADYO ARIZALARI, TIKANMIS TUVALET, LUMBUZLARDAKI KIRAGI, ARIZALI RADAR EKRANI VE UYKUSUZLUKTU. FAKAT HERSEYE KARSIN, COK BASARILI BIR SEYIRDI. ASTRONOTLAR, GEMININ SADECE BIR YUZUNU DAIMA GUNES'E CEVIREREK BIRKAC SAAT ISITTILAR, DOGAL OLARAK DIGER TARAF DA DONDU. BOYLECE

GEMININ ISISAL OZELLIKLERI SAPTANMIS OLDU. MEKANIK KOLA YERLESTIRILEN BIR CIHAZLA, UZAY GEMISI CEVRESINDEKI PARCACIKLAR VE ELEKTRIK ALANLARI OLCULDU. MEKANIK KOLUN HAREKETINI SUREKLI DENETIM ALTINDA TUTMAK ICIN KOL UZERINE YERLESTIRILEN TELEVIZYON KAMERASI ARIZALANINCA, PERSONEL AYNI ISI YAPABILMEK ICIN BILDIGIMIZ AVCI DURBUNU KULLANMAK ZORUNDA KALDILAR. ILK UCUS GUNUNUN SONUNDA, YERYUZU'NDEN HAVALANIRKEN LUMBUZ KORUYUCUSUNU KIRAN BEYAZ MADDENIN, GEMININ BAS KISMINDAN KOPAN ISI KORUYUCU OLDUGUNU KESFETTILER. PERSONEL ILK GUN HICBIR SEY YIYEMEDI. AYRICA PILOT, AGIRLIKSIZ ORTAMA ALISAMADIGINDAN UYUYAMADI; DOLAYISIYLA DA IKINCI GUN COK YORGUN DUSMUSTU. BU DURUMU PILOT SU SOZLERLE DILE GETIRIYORDU: "KENDIMI, SANKI HER ON DAKIKADA BIR MARATON KOSUYORMUS GIBI HISSETTIM." BU SEYIRDE AYRICA ARI, PERVANE, VE, SINEKLERDEN OLUSAN HAYVANLARIN, AGIRLIKSIZ ORTAMDA DAVRANISLARI INCELENDI. ARILAR UCMAKTAN YORULDUKLARINDA, AMACSIZ BIR SEKILDE OLDUKLARI YERE DONUYORLARDI. GEMI DUNYA'YA DONDUGUNDE TUM ARILAR OLMUSTU. PERVANELER CILGIN BIR SEKILDE KANAT CIRPTILAR; SINEKLER HEP YURUDULER. PILOT UCMAK ICIN CALISAN BIR SINEGI ASLA GORMEDIGINI SOYLUYORDU. INISIN YAPILACAGI EDWARDS HAVA KUVVETLERI USSU'NDEKI KURU GOL YATAGI MEVSIMIN DE ETKISIYLE INIS GUNU IYICE ISLANMISTI. BU NEDENLE, INIS ORAYA DEGIL DE, NEW MEXICO'DAKI LIMANA YAPILDI. FAKAT INISIN YAPILACAGI GUN KUVVETLI BIR FIRTINA PATLAMIS VE INISIN YAPILACAGI ALAN, SEYIRDEKI GEMIDEN DAHI RAHATCA GORULEBILEN BEYAZ BIR TOZ BULUTU ALTINDA KALMISTI. BU NEDENLE UCUS BIR GUN GECIKTIRILDI. DORDUNCU UCUS, 27 HAZIRAN- 4 TEMMUZ 1982 ARASI GERCEKLESTIRILDI. BU SEYIR DIGERLERINDEN IKI YONDEN FARKLIYDI. BIRINCISI, ASKERI AMACLI YUK TASIYORDU. HAVA KUVVETLERI YUKUN NE OLDUGUNU ACIKLAMADI. FAKAT BU GIZLI YUKUN, KIRMIZIOTESI ARAMA VE TARAMA YAPAN BIR ALET OLDUGU BILINIYORDU. IKINCI FARKLI YON, OGRENCILERIN HAZIRLADIGI 90 KG. AGIRLIGINDAKI DENEY PAKETININ TASINMASIYDI. BU SEYIRDE

YAPILAN BIR BASKA DENEY DE BAZI BIYOLOJIK MATERYALIN BIRBIRLERINDEN AYRILMASIYDI. DENEYI YAPAN ALET, BU MATERYAL KARISIMI BIR ELEKTRIK ALANA KOYUYOR VE ONLARI DOGAL ELEKTRIK YUKLERINE GORE SECEBILIYORDU. DUNYA USTUNDE BU ISLEMI, YERCEKIMI ETKILEMEKTE ELEKTRIK YUKU, SICAKLIK VE CALKANTIYA NEDEN OLMAKTA, DOLAYISIYLA DA MATERYAL TEKRAR BIRBIRINE KARISMAKTADIR. UZAYDA BU MATERYALLERI BIRBIRINDEN AYIRMANIN, 800 KEZ DAHA ETKIN OLDUGU ORTAYA CIKARILDI. BU SON DENEME UCUSUYDU. BUNDAN SONRAKI UCUSLAR, NORMAL TICARI AMACLI OLACAKTI. DORDUNCU UCUSTA BASARIYA ULASAMIYAN EN ONEMLI NOKTA, KATI YAKITLI ROKETLERIN PARASUT MEKANIZMASININ ARIZALANMASI VE HER BIRI 7 MILYAR TL'NA MAL OLAN BU ROKETLERIN DENIZ DIBINI BOYLAMASIYDI. BESINCI UCUSUN PERSONEL SAYISI, ILK KEZ IKIDEN FAZLA OLUYORDU. UCUS KOMUTANI VE PILOTTAN BASKA, WILLIAM VEJOSEPH ADLI IKI ASTRONOT DA UCUS UZMANI OLARAK GEMIDE YER ALDILAR. GEMININ ILK TICARI YUKU OLAN ILETISIM UYDULARI 11 KASIM 1982 GUNU BASLAYAN BU SEFERDE BASARIYLA YORUNGEYE OTURTULDU. EGER BU UYDULAR YERDEN YORUNGEYE YERLESTIRILSEYDI, UYDU SAHIPLERI DAHA FAZLA PARA ODEMEK ZORUNDA KALACAKLARDI. BU SEYIRDE PERSONELI UZAY TUTTU. BU YUZDEN UZAYDA YURUYUS IZLENCESI BIR GUN ERTELENDI. ERTESI GUN ISE HER BIRI YARIM MILYAR TL'NA MAL OLAN UZAY MELBUSATI ARIZALANDI. TUM UGRASLARA KARSIN ARIZALAR GIDERILEMEDIGI ICIN YURUYUSTEN VAZGECILDI. FAKAT BU COK ONEMLI BIR DENEYDI; CUNKI GELECEKTE UZAY LIMANI GIBI BUYUK YAPILAR INSA EDILIRKEN, BU TECHIZAT ILE ARAC DISI CALISMALAR YAPILACAK.

B. PROGRAMS

Two programs are used to find the frequencies of the symbols in the magazine articles given above. A Fortran program creates a data set format which can be processed by SAS program. The program which sets the logical record length of data file to 1, is given below.

```
//SUHA1    JOB (2979,5555),'SUHA',CLASS=A
//*MAIN ORG=NPGVM1.2979P
//  EXEC FORTVCG
//FORT.SYSIN DD *
C         THIS PROGRAM CONVERTS ONE LOGICAL RECORD OF
C         EIGHTY CHARACTERS TO EIGHTY
C         LOGICAL RECORDS OF ONE CHARACTER EACH.
C
C            UNIT 5: INPUT
C            UNIT 1: OUTPUT
C
      DIMENSION A(80)
      LINES = 0
   10 CONTINUE
      READ(5,20,END=100) A
   20 FORMAT(80A1)
      LINES = LINES + 1
      DO 30 I=1,80
      WRITE(1,20) A(I)
   30 CONTINUE
      GO TO 10
  100 CONTINUE
      WRITE(6,110) LINES
  110 FORMAT(1X,'NUMBER OF LINES READ: ',I7)
      STOP
      END
/*
```

```
//GO.FT01F001 DD UNIT=3350,VOL=SER=MVS004,
DISP=(NEW,KEEP),
//    DCB=(RECFM=FB,LRECL=1,BLKSIZE=6000),
//    SPACE=(TRK,(1,1)),DSN=S2979.LETTER
//GO.SYSIN DD *
      Insert text here.  (Also, remove this line).
/*
//
```

The second program is run to count the frequency of each type of letter. This SAS program is given below.

```
//SUHA4    JOB (2979,5555),'SUHA',CLASS=B
//*MAIN ORG=NPGVM1.2979P
//  EXEC SAS
//TEXT  DD UNIT=3350,VOL=SER=MVS004,DISP=SHR,
DSN=S2979.ALPHA1
//SYSIN DD *
OPTIONS LINESIZE = 80;
DATA TEXT;
    INFILE TEXT;
    INPUT  @1 LETTER $CHAR1. ;
    IF LETTER EQ ' ' THEN DELETE;
PROC FREQ DATA=TEXT;
    TABLES LETTER;
/*
//
//SUHA4    JOB (2979,5555),'SUHA',CLASS=B
//*MAIN ORG=NPGVM1.2979P
//  EXEC SAS
//TEXT  DD UNIT=3350,VOL=SER=MVS004,DISP=SHR,
DSN=S2979.ALPHA1
//SYSIN DD *
OPTIONS LINESIZE = 80;
DATA TEXT;
    INFILE TEXT;
    INPUT  @1 LETTER $CHAR1. ;
    IF LETTER EQ ' ' THEN DELETE;
PROC FREQ DATA=TEXT;
    TABLES LETTER;
/*
//
```

APPENDIX B

THE LISP PROGRAM OF CODING PROCESS

```
(defun huffman (P)
  (sortcar (assign (arrange (mapcar 'list P))) 'greaterp))

(defun arrange (Q)
  (cond ((null (cdr Q)) Q)
        (t (arrange (insert (list (add (caar Q) (caadr Q))
                                  (car Q) (cadr Q))
                            (cddr Q)) )) ))

(defun insert (x Q)
  (cond ((null Q) (cons x Q))
        ((lessp (plus (car x) E) (caar Q)) (putin N x Q))
        (t (cons (car Q) (insert x (cdr Q)) )) ))

(defun putin (n x L)
  (cond ((zerop n) (cons x L))
      ((null L) (list x))
      (t (cons (car L) (putin (subl n) x (cdr L))))))

(defun assign (Q) (split nil (car Q)) )

(defun split (c L)
  (cond ((null (cdr L)) (list (list (car L) c)) )
        (t (append (split (cons 1 c) (cadr L))
                   (split (cons 0 c) (caddr L)) )) ))

(defun sortcode (L)
  (cond ((null L) nil)
   (t (inscode (caar L) (cadar L) (sortcode (cdr L)) )) ))

(defun inscode (p c L)
  (cond ((null L) (list (list p c)) )
   ((greaterp (length c) (length (cadar L)))
```

```
    (cons (list p (cadar L)) (inscode (caar L) c (cdr L)) ))
      (t (cons (list p c) L)) ))

(defun totlength (L)
  (cond ((null L) 0)
        (t (add (times (caar L) (length (cadar L)) )
                (totlength (cdr L)) )) ))

(defun avglength (L)
  (quotient (times 1.0 (totlength L))
            (apply 'add (mapcar 'car L)) ))

(defun varlength (L)
  (quotient (times 1.0 (varlength2 L (avglength L)))
            (apply 'add (mapcar 'car L))))

(defun varlength2 (L mu)
  (cond ((null L) 0)
        (t (add (times (caar L)
              (expt (difference (length (cadar L)) mu) 2))
             (varlength2 (cdr L) mu)))))

(defun Zipf (n)
  (cond ((zerop n) nil)
        (t (cons (quotient 1.0 n) (Zipf (- n 1)) )) ))

(defun tryN (n e)
  (set 'N n)
  (set 'E e)
  (set 'code (sortcode (huffman Turkish)) )
  (print (list 'N '= n 'E '= e))
  (pp code)
  (print (list 'mean '= (avglength code))) (terpr)
  (print (list 'variance ' = (varlength code))) (terpr))

(set 'Turkish
 '(0.0 0.00006 0.00006 0.00017 0.00028 0.00034
   0.00039 0.00045 0.00045 0.00056 0.00061 0.00067
```

```
    0.00067 0.00073 0.00073 0.00084 0.00084 0.00089
    0.00112 0.00134 0.00162 0.00196 0.00358 0.00581
    0.00687 0.00872 0.00989 0.01017 0.01224 0.01637
    0.01883 0.02185 0.02660 0.02682 0.02945 0.03213
    0.03509 0.03861 0.03984 0.05130 0.05163 0.06085
    0.06611 0.07952 0.09427 0.10528 0.13339))

(set 'N 0)
(set 'E 0)
```

APPENDIX C

THE SAS POGRAM USED FOR FINDING THE BUFFER SIZE

```
//SUHA6    JOB (2979,5555),'SUHA',CLASS=B
//*MAIN ORG=NPGVM1.2979P
//  EXEC SAS
//DATAIN DD UNIT=3350,VOL=SER=MVS004,DISP=SHR,DSN=S2979.ALPHA1
//SYSIN  DD *
DATA ONE;
    INFILE DATAIN;
    INPUT LETTER $ 1;
DATA ONE;
    SET ONE;
    *                                                    ;
    *     For each letter, assign its number of bits     ;
    *     in the used code.                              ;
    IF LETTER EQ '/' THEN BITS =   ;
    IF LETTER EQ 'I' THEN BITS =   ;
    IF LETTER EQ 'A' THEN BITS =   ;
    IF LETTER EQ 'E' THEN BITS =   ;
    IF LETTER EQ 'N' THEN BITS =   ;
    IF LETTER EQ 'R' THEN BITS =   ;
    IF LETTER EQ 'U' THEN BITS =   ;
    IF LETTER EQ 'L' THEN BITS =   ;
    IF LETTER EQ 'S' THEN BITS =   ;
    IF LETTER EQ 'K' THEN BITS =   ;
    IF LETTER EQ 'P' THEN BITS =   ;
    IF LETTER EQ 'T' THEN BITS =   ;
    IF LETTER EQ 'M' THEN BITS =   ;
    IF LETTER EQ 'Y' THEN BITS =   ;
    IF LETTER EQ 'O' THEN BITS =   ;
    IF LETTER EQ 'G' THEN BITS =   ;
    IF LETTER EQ 'B' THEN BITS =   ;
```

```
    IF LETTER EQ 'C' THEN BITS =   ;
    IF LETTER EQ ',' THEN BITS =   ;
    IF LETTER EQ '.' THEN BITS =   ;
    IF LETTER EQ 'Z' THEN BITS =   ;
    IF LETTER EQ 'V' THEN BITS =   ;
    IF LETTER EQ 'P' THEN BITS =   ;
    IF LETTER EQ 'H' THEN BITS =   ;
    IF LETTER EQ 'F' THEN BITS =   ;
    IF LETTER EQ '0' THEN BITS =   ;
    IF LETTER EQ '''' THEN BITS =  ;
    IF LETTER EQ '1' THEN BITS =   ;
    IF LETTER EQ '"' THEN BITS =   ;
    IF LETTER EQ '2' THEN BITS =   ;
    IF LETTER EQ ')' THEN BITS =   ;
    IF LETTER EQ '5' THEN BITS =   ;
    IF LETTER EQ '3' THEN BITS =   ;
    IF LETTER EQ '8' THEN BITS =   ;
    IF LETTER EQ '(' THEN BITS =   ;
    IF LETTER EQ '4' THEN BITS =   ;
    IF LETTER EQ ';' THEN BITS =   ;
    IF LETTER EQ '9' THEN BITS =   ;
    IF LETTER EQ 'J' THEN BITS =   ;
    IF LETTER EQ '6' THEN BITS =   ;
    IF LETTER EQ 'W' THEN BITS =   ;
    IF LETTER EQ ':' THEN BITS =   ;
    IF LETTER EQ '7' THEN BITS =   ;
    IF LETTER EQ '-' THEN BITS =   ;
    IF LETTER EQ '?' THEN BITS =   ;
    IF LETTER EQ 'X' THEN BITS =   ;
    IF LETTER EQ 'Q' THEN BITS =   ;
DATA ONE;
    *                                                     ;
    *    Let RATE = Output capacity of the processor in   ;
    *               bits per unit time.                   ;
    *                                                     ;
```

```
    SET ONE;
    RATE = 4.30771;
    BUFFER + BITS;
    BUFFER = BUFFER - RATE;
    IF BUFFER LE 0 THEN BUFFER = 0;
OPTIONS LINESIZE =80;
PROC FREQ  DATA=ONE;
    TABLES BUFFER;
PROC MEANS DATA=ONE MEAN STD MIN MAX;
    VAR BUFFER;
/*
//
```

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c.1 Modification of Huffman Coding.